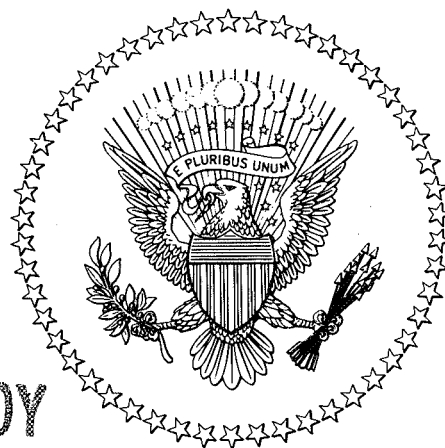


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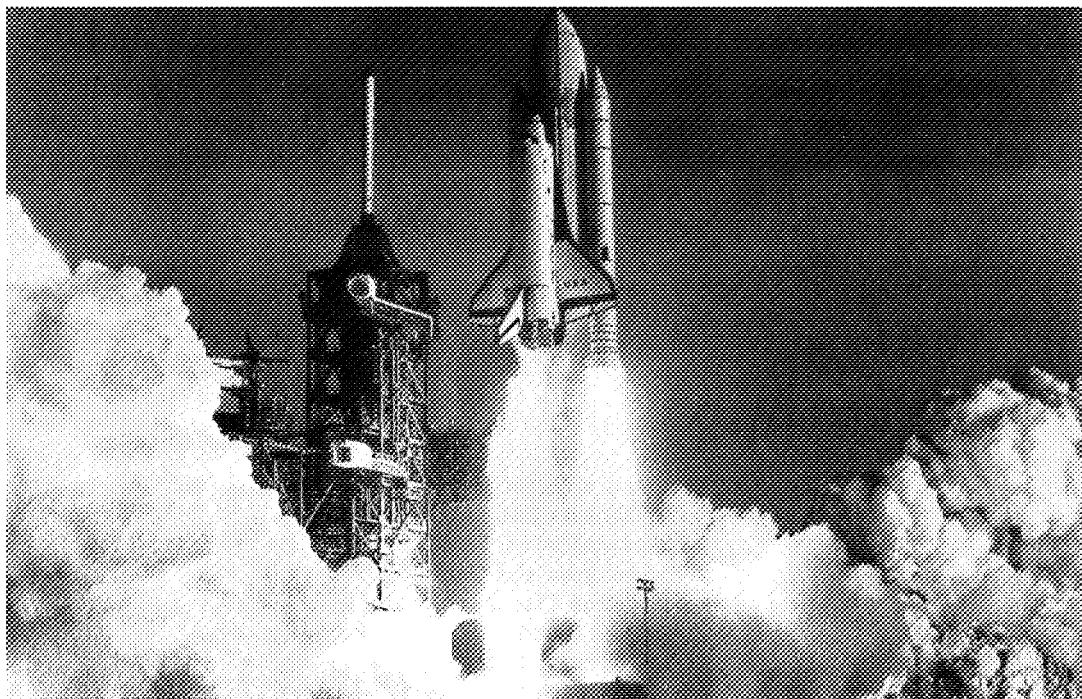


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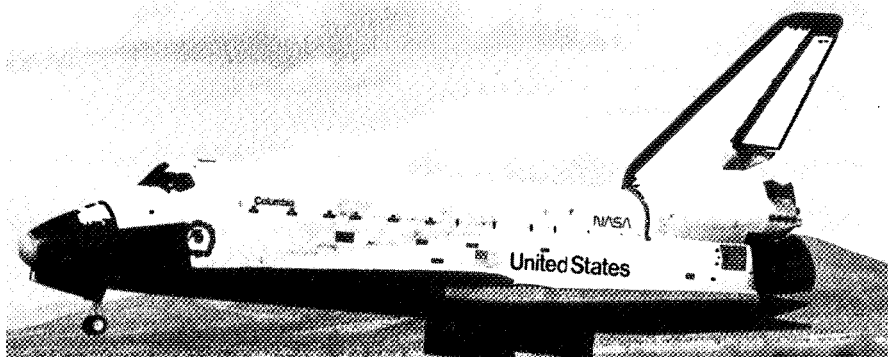
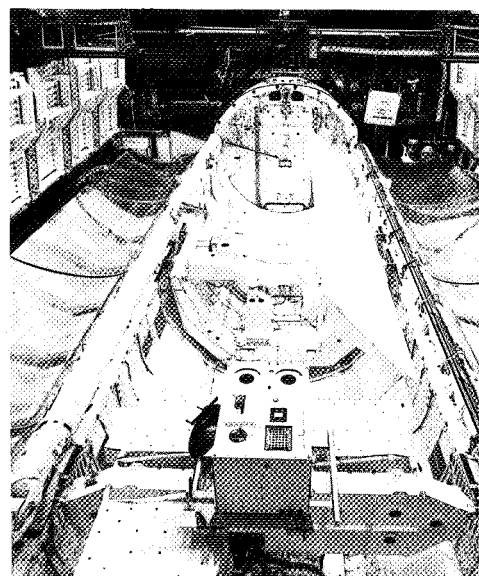
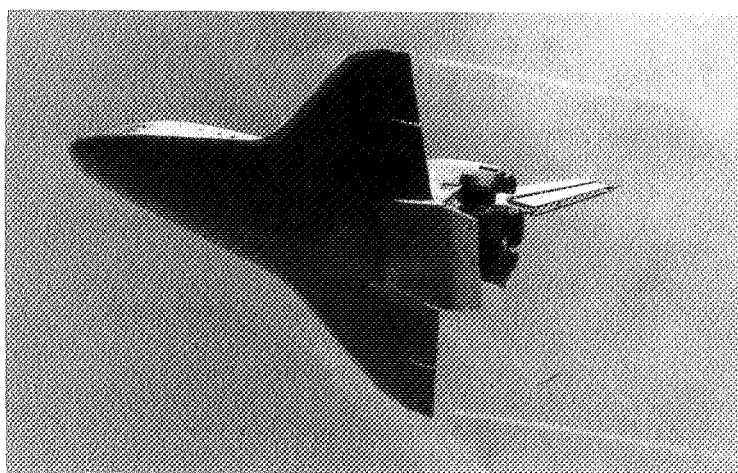
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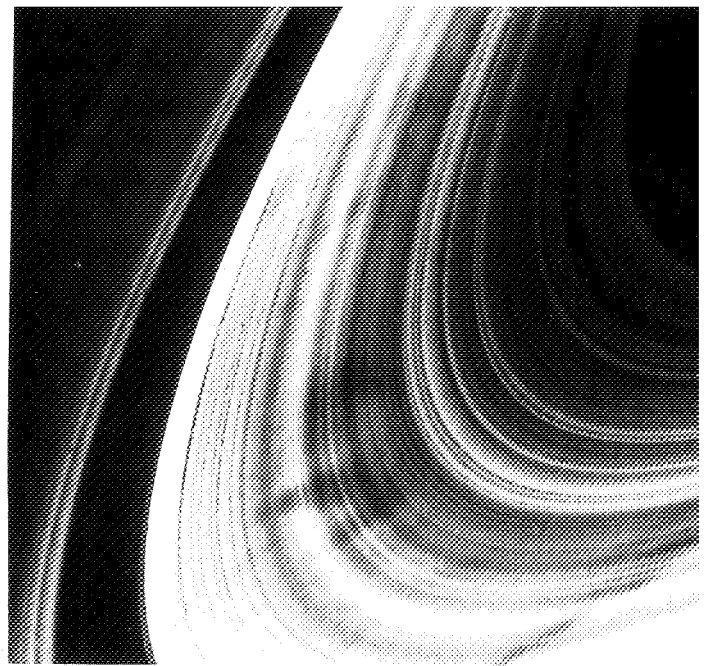
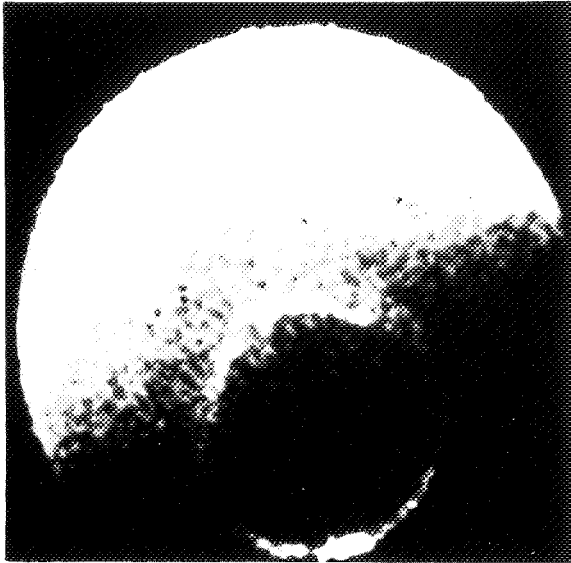
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Aerospace Events of 1981

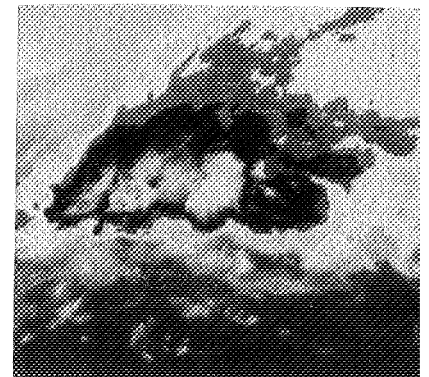
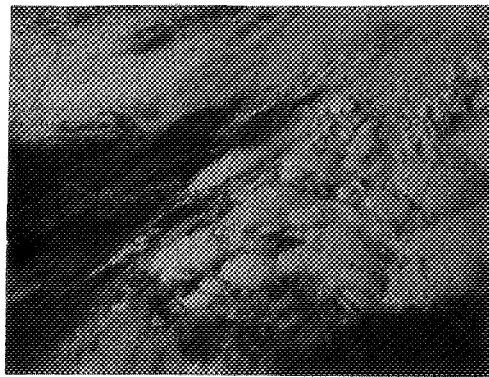


A new era in space: the Space Shuttle *Columbia* (above) rises on its maiden flight into orbit, carrying astronauts John Young and Robert Crippen from Kennedy Space Center on 12 April 1981 to test the Shuttle systems before landing for launch again. Below center, *Columbia* glides toward Edwards Air Force Base, California, for a smooth landing (bottom) after completing its second flight into space, 12–14 November, piloted by Joe Engle and Richard Truly. Below right, the OSTA 1 pallet, carrying remote earth-sensing experiments, is cradled in the Shuttle's cargo bay for that second flight. The crew quarters are ahead, and the remote manipulator arm lies at left along the side of the bay awaiting its first testing in orbit.

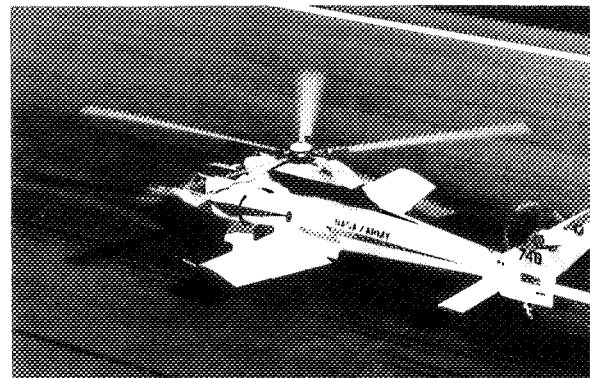
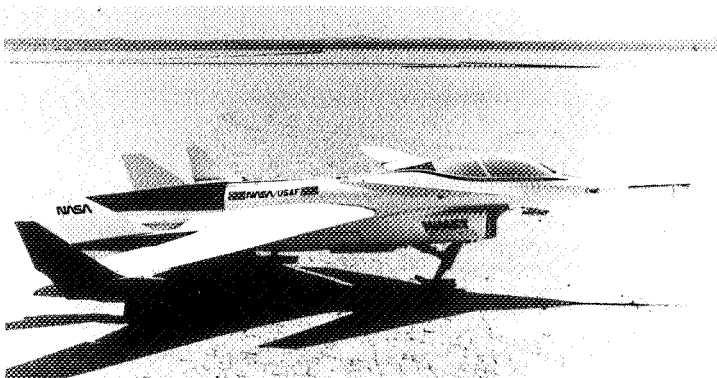




Spacecraft continued to explore the planets and monitor Earth. *Voyager 2* took the high-resolution picture of Saturn's rings, upper right, 22 August from 4 million km away. Scientists are studying "spoke" features in the B ring for clues to their origins. Above left, an image from a Dynamics Explorer, launched in August to study energy exchanges between the magnetosphere and ionosphere and the causes of auroras, includes the first picture of Earth's entire auroral oval (the smaller circular feature), taken 15 September from 22 km above the North Pole. At right, an image sent back by the *Goes 4* environmental satellite in the spring of 1981 and an enhanced infrared image (far right) show thunderstorms.



HiMAT no. 2 (highly maneuverable aircraft technology research aircraft), below left, rests on the dry lakebed near Dryden Flight Research Facility poised for flight to test high-risk technology for future fighter aircraft in a NASA-Air Force program. During 1981, flights pushed toward transonic speeds, reaching mach 0.95. Below right, the NASA-Army RSRA rotor systems research aircraft takes off from Ames Research Center at Moffett Field as a "flying wind tunnel" to investigate advanced helicopter systems.



Summary

The United States space program opened a new era in 1981 with two orbital flights of the Space Shuttle *Columbia*—the first spacecraft to lift off into space, return after its mission, and lift off to orbit the earth again. Even as *Columbia* prepared for a third orbital test flight and the goal of flexible, routine access to space came nearer, other spacecraft made discoveries about the solar system, the universe, and the interactions of the sun with the earth's environment.

Voyager 2, flying past Saturn in August, returned finely detailed closeup photos and scientific data that added to and also brought new insights into the information *Voyager 1* had returned in 1980. New theories about the planet's complex ring structure and surveys of nearly all of Saturn's 17 moons occupied scientists as *Voyager 2* flew on toward a January 1986 encounter with Uranus (and later, possibly, with Neptune). Two Dynamics Explorers and a Solar Mesosphere Explorer satellite began studying the effects of solar emissions on Earth.

The year's 18 launches—2 Shuttle flights plus 16 out of 17 attempts with expendable launch vehicles—orbited 20 spacecraft, most of them for daily service to dwellers on the earth. Besides the Shuttle flights and the three NASA scientific satellites, six privately or internationally owned satellites were added to growing communications networks, two to continuous weather services, and six to navigation and defense systems. A small scientific satellite was launched for radio amateurs and schools as a secondary payload with a NASA satellite.

Remote-sensing satellites, sounding rockets, aircraft, and balloons, as well as instruments on the Shuttle, returned information on the earth's resources and atmosphere for increasing use by numerous nations. Research and development advanced spacecraft concepts, new technology for military and civilian aircraft and airways, and use of wind, nuclear, and solar energy.

This summary chapter surveys 1981 achievements in the U.S. aeronautics and space program by function. The following chapters present the work of individual agencies in more detail.

Communications

More than half NASA's launches in 1981—6 out of 11—orbited communications satellites, 5 for the

rapidly expanding international and domestic industry and 1 for the Department of Defense network for command and control of U.S. military forces.

Operational Space Systems

INTELSAT. Launch of the second and third Intelsat V satellites—each capable of transmitting 12 000 voice conversations and 2 TV channels—upgraded the global service of the International Telecommunications Satellite Organization. INTELSAT planned up to 6 more Intelsat V launches in the next two years, followed by 6 improved Intelsat V-As, to meet expected doubling of international traffic demands in the next four years. Evaluation of industry proposals for the advanced Intelsat VI series also began in 1981.

Domestic Communications Satellites. Three commercial domestic satellites were launched in 1981: Comsat General Corporation's *Comstar D-4*, RCA American Communications' *RCA-Satcom 3*, and Satellite Business Systems' *SBS 2*. At the end of the year, 11 domestic communications satellites were in operation, 3 in the RCA system, 3 in Western Union's Westar system, 3 in AT&T's Comstar system, and 2 operated by SBS. More than 5000 ground stations were licensed for satellite digital, TV, and voice service.

Eight companies were preparing 28 satellites to replace or add to those already in service. Among them, the Space Communications Company scheduled the first Tracking and Data Relay Satellite (TDRS) for Shuttle launch early in 1983. The first and second satellites in the TDRS System—Advanced Westar System will provide service to the government; a third (the first advanced Westar) will provide commercial service; and a fourth, both TDRSS (leased to government) and commercial service.

The Federal Communications Commission in November requested comments from industry and the public on costs and benefits of reducing to 2° the spacing in orbit for the next generation of communications satellites, to accommodate increased numbers. Comments were being received before FCC made final orbital assignments in 1982.

Military Communications Satellites. The fifth of DoD's Fleet Satellite Communications System satellites

was launched in August, but structural damage limited its operations. The constellation of four satellites already in orbit continued to provide high-priority global communications for the Navy, the military commands, and the strategic forces. Equipment for secure voice communications had been installed on 431 ships by the end of 1981. The Navy revised plans for its LEASAT satellites—eventually to replace the FLTSATCOM satellites—to fit Space Shuttle availability, planning the first launch for 1984.

The Army continued to upgrade ground terminals for strategic and tactical communications. The Defense Advanced Research Projects Agency, Army, and Navy advanced technologies for airborne and ground terminals and also for laser communications from space to submarines. Advanced development models were delivered to DoD for testing an airborne satellite terminal for secure communications between aircraft and missiles under severe jamming.

Marisat. During 1981, the Marisat system managed by Comsat General Corp. almost doubled its commercial maritime service, reaching 950 ships by the end of the year. In February 1982, the International Maritime Satellite Organization (INMARSAT) will take over and expand service still further, expecting 2000 ship terminals in use by 1985 and at least 5000 by 1990.

Military Navigation Satellites. *Nova 1*, a new longer-life satellite, was launched in May to expand the Navy's Navigation Satellite System, TRANSIT, as that system completed its 16th year of operation. Full-scale development continued on the Global Positioning System (GPS), already providing the Army, Navy, and Air Force up to six hours a day of accurate positioning with five Navstar satellites. Designed to improve weapon delivery and rapid force deployment, GPS will also aid in mapping and geodesy. Landsat-D, to be launched in 1982, will use GPS to determine satellite positions for correlation of earth photography.

Space Communications Experiments

Experimental Satellites. NASA's *ATS 1* and *3* applications satellites continued emergency public communication service and educational experiments into their 14th and 15th years. NOAA-E, the first satellite equipped to participate in the planned interagency and international SARSAT satellite-aided search and rescue system, was being prepared for early 1983 launch.

Communications Research. NASA called for designs from industry and pursued technology development in 1981 to study the use of the 30- to 20-gigahertz frequency band, for relief of future congestion in geostationary orbit. DoD developed a conceptual design for a new worldwide, jam-resistant, military communications system, MILSTAR, to

operate at extremely high frequency and link all military forces.

Communications Negotiations. The FCC Advisory Committee established in 1981 met on policy issues and planning for the World Administrative Radio Conference (Space WARC) to be held in July 1985, with a second session in 1987. The conference will seek to guarantee all countries equitable access to the geostationary satellite orbit and service frequencies.

Direct Broadcast Satellites. FCC proposed, and received comments on, interim rules and frequencies for direct broadcast satellites. Final rules for planned interim systems were to be adopted in 1982. FCC tentatively accepted eight applications to provide direct broadcast service, and studies continued in preparation for the Region 2 Administrative Radio Conference in June 1983.

Earth's Resources and Environment

Remote-sensing instruments surveying the earth's surface from newly launched and already orbiting satellites, from the Space Shuttle, and from aircraft and balloons returned information on mineral and oil deposits, land and water use, crop conditions, geodynamics, marine conditions, weather, pollution, and atmospheric constituents and changes.

Inventorying and Monitoring

Earth Resources. The imaging radar (SIR-A) and the multispectral infrared radiometer (SMIRR) flown on the Space Shuttle in November showed earth terrain features not previously mapped from space, returning data on rock distribution, faults, and other geologic features. The joint NASA-industry Geosat Test Case Project showed that remote sensing can provide geologic information not commonly obtained from field mapping—such as location of clays associated with specific mineral deposits. The Department of the Interior found that data from NASA's *HCMM* (Heat Capacity Mapping Mission) launched in 1978 may aid in finding oil and gas deposits.

Landsat-D development progressed toward a summer 1982 launch, as *Landsat 2* and *3* earth resources satellites continued during 1981 to provide worldwide multispectral imagery of many kinds of resources for commercial and government users in the United States and other countries. Landsat-D's thematic mapper will extend spectral range and improve resolution and accuracy. The National Oceanic and Atmospheric Administration of the Department of Commerce prepared to assume operation of the land-observing satellite system from NASA, taking operational control of Landsat-D in 1983. NOAA also will develop a management system to ensure eventual smooth transfer to the private sector.

Among users in 1981, the Department of the Interior applied Landsat data to mapping land cover, identifying vegetation for planning land use and fire control, and monitoring mining and water use. DOI trained 240 U.S. and foreign scientists and technicians in remote sensing during 1981. Sales of remotely sensed data totaled \$4.3 million.

In the multi-agency AgRISTARS program, tests showed that remote sensing can provide data to help prepare accurate preharvest crop estimates, warning of changes in soil moisture, and improved resources management. Accuracy and efficiency in classifying crops improved. Continuing for its second year, the program used data gathered by satellites and aircraft in developing estimates of precipitation, solar radiation, temperatures, snowcover, and vegetation.

Monitoring the Seas. Analysis of data received earlier from the *Seasat* remote-sensing satellite improved accuracy of the marine geoid and knowledge of sea surface temperatures, currents, wind, and waves. *Nimbus 7*, orbiting since October 1978, demonstrated that chlorophyll measured from space could be used to assess marine productivity. The National Marine Fisheries Service used Landsat data to quantify changes in productivity, biomass, and areas of principal coastal-zone habitats.

Environmental Analysis and Protection

Weather Satellite Operations. The *Goes 5* Geostationary Operational Environmental Satellite and *Noaa 7*, launched in May and June 1981, joined *Goes 4* and *Noaa 6* to make up the Department of Commerce's four operational environmental satellites, taking over from *SMS 2* and *Tiros-N*. The polar-orbiting NOAA satellites observe the entire earth four times a day, providing data to more than 120 countries. The geostationary *Goes 4* and *5* observe most of the Western Hemisphere. Continuous satellite observations of severe storms continued to aid the National Weather Service in weather prediction and warning, reducing severity of effects of natural disasters on life and property. Global data improved the accuracy of five-day and one-week forecasts in 1981, and the experimental VISSR atmospheric sounder (VAS) on *Goes 4* and *5* proved that atmospheric temperature and moisture can be mapped from space to improve storm predictions. VAS data aided detection of jet streams, storm systems developing in the upper atmosphere, and hurricanes.

Some 120 countries received NOAA data directly, with medium-resolution images going to some 890 locations; high-resolution data go to 25 countries. Weather facsimile broadcasts from geostationary satellites go to 30 Western Hemisphere countries, Australia, and New Zealand. Foreign governments also contribute instruments to the polar-orbiting spacecraft.

Atmospheric Research. Nearly global satellite data, as well as aircraft and balloon data, contributed to analyses of stratospheric constituents and dynamics and also advanced the understanding of the chemistry of the lower atmosphere. *Nimbus 7* observations of the stratosphere will aid understanding of the earth's radiation balance. In addition, findings made with a climate model developed by the Goddard Laboratory for Atmospheric Sciences may have important effects on medium-range weather forecasting.

Space Science

Space science programs use spacecraft, suborbital vehicles, and ground facilities to investigate the origin and evolution of life, the earth, the solar system, and the universe. Most immediately, they investigate processes affecting the earth's environment, including interactions of emissions from the sun with the layers of the earth's environmental shell.

Sun-Earth Studies

NASA's two Dynamics Explorer satellites—*DE 1* and *2* launched in August 1981—began studying interactions of the earth's magnetosphere and ionosphere, and in October the Solar Mesosphere Explorer *SME* began examining changes in the mesosphere ozone densities caused by solar ultraviolet flux. The three International Sun-Earth Explorers launched in 1978 continued to add information on interactions of the solar wind and outer limits of the atmosphere, which control the earth's near-space environment.

NASA and the Federal Republic of Germany began work on two cooperative Active Magnetospheric Particle Tracer Explorers (AMPTs), for a dual launch to study sun-earth interactions through active chemical release. The Explorers will examine the motions and energization of ions outside and inside the magnetosphere.

Study of the Planets

Saturn. *Voyager 2*'s August 1981 encounter with Saturn sent back more spectacular photos and new scientific detail on the giant planet, its ring structure, and moons—adding to the rich harvest returned by *Voyager 1* in 1980 and possibly revising conclusions. The new observations from *Voyager 2* suggest that areas of Saturn's rings thought to consist of thousands of individual ringlets are alternating bands of material at increased and decreased densities. Pressure waves set up by resonances between Saturn and its satellites are being considered as possible reasons for these structures. The surfaces of nearly all the 17 moons of Saturn were examined in detail.

At the year's end, *Voyager 2* continued toward a January 1986 meeting with Uranus and then possibly an encounter with Neptune, two planets of which we know little because of their great distances from Earth. *Voyager 1* flew toward the outer solar system, its instruments studying the interplanetary environment.

Jupiter. Some flight hardware was in production for NASA's *Galileo* orbiter and probe mission to Jupiter, scheduled for launch in the mid-1980s. The orbiter is to fly as close as 200 kilometers from Jupiter's satellites, and the probe is to descend into the planet's atmosphere for detailed measurements.

Mars. Viking Lander 1 continued scientific observations in its sixth (Earth) year on the surface of Mars. Analysis of data sent back earlier by the orbiters and landers of the *Viking 1* and 2 missions, as well as Earth-based radar measurements, has revealed much about the present state of Mars and its past history. Layers in the North polar cap hold the key to understanding the climate changes on that planet as they do on Earth, while measurements indicate surface water to be stored globally as ground ice.

At the National Air and Space Museum's Center for Earth and Planetary Studies, investigations of the ridges on Mars added to the knowledge of Martian tectonics and indicated the timing of geologic events in regions surrounding the Tharsis region.

Venus. The *Pioneer-Venus* orbiter, circling Venus into its fourth Venusian year, continued to return data on the atmosphere of that neighbor of Earth and on the solar wind. Venus was found to have two different cloud states, alternating in dominance. Meanwhile, NASA continued to define a proposed mission for the Venus Orbiting Imaging Radar (VOIR) to map the entire surface of Venus.

Interplanetary Space. Interplanetary probes *Pioneer 6* to *11*, launched in earlier years, continued to function well. *Pioneer 10*, which flew by Jupiter in 1973, and *Pioneer 11*, which flew past Jupiter in 1974 and Saturn in 1979, journeyed through the outer solar system, measuring solar and galactic phenomena. *Pioneer 10*, 3.7 billion km from the sun in July, revealed that the solar wind ends (the boundary of the heliopause) farther from the sun than predicted. *Pioneer 6*, launched in 1965, also was still providing information on the solar wind.

Ground-Based Research and Analysis. The Infrared Telescope Facility in Hawaii obtained data on Uranus and searched for a ring system around Neptune. The telescope found spectral evidence of propane on Titan and water on Iapetus, both moons of Saturn.

Study of the Universe

Research with Spacecraft. The last two HEAO spacecraft in a highly successful series ended operations in 1981. The x-ray telescope on *Heao 2* (*Einstein*) brought revisions in almost every area of high-

energy astrophysics. *Heao 3* findings suggest the possibility of a massive black hole at the center of our galaxy.

The International Ultraviolet Explorer *IUE* operated well in its third year, making ultraviolet spectroscopic measurements of supernova remnants, the interstellar medium, and cataclysmic variables. Smithsonian studies of mass loss in cool stars, using *IUE* data, indicated a consistent and continuous evolution of coronas, wind characteristics, and mass-loss rates, varying from the hot, fast winds and low mass-loss rate of the sun to the slow, cool winds and high mass-loss rate of the coolest giant and supergiant stars.

Another international Explorer, the NASA-United Kingdom-Netherlands Infrared Astronomical Satellite *IRAS*, was being prepared to carry a cryogenically cooled telescope into orbit in 1983. Construction of NASA's *Space Telescope* progressed toward a 1985 launch, and highly sensitive instruments were selected for the future Gamma Ray Observatory *GRO*.

Research from Suborbital Vehicles. Sounding rockets, balloons, and high-flying aircraft continued to make new observations. A joint sounding-rocket experiment, by the Smithsonian and France, measured the soft x-ray spectrum of the North Polar Spur.

Research from the Ground. National Science Foundation-supported scientists—using the Kitt Peak National and Lick Observatories—identified two galaxies receding so rapidly that they are thought to be 10 billion light-years from Earth, indicating that astronomers have now looked more than halfway back to the believed moment of the creation of the universe.

Life Sciences

NASA made significant achievements in research to maintain the health of man in space, developing several countermeasures to cardiovascular deconditioning and testing new drugs for motion sickness. Biomedical experiments were being defined to support this and other research for the first Spacelab mission dedicated to life sciences. Research also identified a technique for purifying waste water for reuse during manned missions and the technology for spacesuits that can operate at higher internal pressures. In exobiology, Voyager observations at Saturn's moon Titan confirmed the presence of special organic molecules that provide additional evidence that the chemistry preceding life is widely distributed beyond Earth.

Space Transportation

Halfway through its test program after two orbital flights in 1981, the reusable Space Transportation System moved toward operational status, as expendable vehicles continued to orbit satellites for numerous

customers. Research and testing in other programs continued to improve space vehicles.

Space Transportation System

Designed to provide economical, flexible access to space for NASA, DoD, and other domestic and international users, the Space Transportation System will carry 29 500 kilograms of payload into orbit. NASA's reusable Space Shuttle will orbit satellites, experiments, and laboratories for commercial applications, scientific investigations, and defense needs. The European Space Agency is developing the laboratory modules and instrument pallets making up Spacelab, to fly in the Shuttle's cargo bay. DoD and industry are developing additional rocket stages to boost payloads from the Shuttle into higher orbits.

Space Shuttle. The Shuttle—first spacecraft to orbit the earth and return for relaunch—made its maiden orbital flight in April 1981 and a second orbital test flight in November. Piloted by a two-man crew and powered by three main engines firing simultaneously with two reusable solid-fueled rocket boosters, the orbiter *Columbia* lifted off from Kennedy Space Center. After jettisoning recoverable boosters and the expendable external tank, *Columbia* orbited the earth for two days, verifying systems and performance, before returning to land like an aircraft at Edwards Air Force Base. Refurbished for STS 2, *Columbia* again flew a two-day mission, carrying a second crew, experiments, and a Canadian-furnished remote manipulator arm.

The Shuttle met its major test objectives on both flights, although failure of a fuel cell shortened the second flight from the planned five days. The missions confirmed the reusability of orbiter and boosters and the performance of the engines. Astronauts exercised the manipulator arm and the cargo bay doors, and experiments returned good data.

At the end of the year, *Columbia* was being prepared for its third flight, scheduled for March 1982. After the fourth test flight, the Space Transportation System would fly its first operational mission, STS 5, planned for late 1982. Work on *Challenger*, *Discovery*, and *Atlantis*—the remaining orbiters in production—continued, with *Challenger's* first flight scheduled for early 1983.

Planning for Operations. With operational flights to begin in 1982, space on Shuttle flights is being sold out through 1986. Launch service agreements had been signed with 5 users and deposits made by 14 others by the end of 1981. In addition, the first agreement for launching a small, self-contained payload was signed, to fly experiments for five educational institutions on STS 4. Beginning in 1985, Shuttle missions will be launched from Vandenberg AFB as well as Kennedy.

Spacelab. The first science and applications payload, OSTA 1, flew on the Shuttle in November.

Mounted on an engineering-model pallet from the European Space Agency's Spacelab program, instruments gathered information on earth resources, the oceans, and technology for future instruments. The March 1982 flight will carry a corresponding space science payload, OSS 1, for research in physics, astronomy, and space technology. NASA and the Federal Republic of Germany were preparing OSTA 2, with experiments in materials processing, for launch in early 1983. A suitcase-sized processing experiment was planned for early 1982 flight and on three other missions.

ESA delivered the first Spacelab flight unit, a long module with one pallet, to Kennedy in 1981. The first Spacelab mission, a test of the pressurized laboratory module, is scheduled to carry NASA and ESA experiments in late 1983. Production of the second Spacelab proceeded in Europe.

Inertial Upper Stage. A test launch with the solid-propellant IUS, being developed by DoD to boost payloads from the Shuttle into higher orbits, is scheduled on a Titan launch vehicle in 1982. First launch from the Shuttle is scheduled to place a Tracking and Data Relay Satellite in orbit in early 1983.

Spinning Solid Upper Stage. Development progressed on two sizes of the aerospace industry's solid-fueled SSUS—the Delta-class SSUS-D and the Atlas-Centaur-class SSUS-A—which will launch smaller spacecraft into geosynchronous-transfer orbit from the Shuttle in low earth orbit.

Advanced Programs. NASA studied concepts for free-flying reusable platforms to be deployed in space and serviced by the Shuttle orbiters. For example, it investigated tools to place, retrieve, and repair satellites in orbit.

Expendable Launch Vehicles

The United States launched 18 satellites on 16 expendable vehicles during 1981. For the fifth time in its 23-year history, NASA had a perfect launch vehicle record: 11 for 11. The agency orbited dual payloads on two Delta vehicles for a total of 13 payloads for the year—all but 3 for other users. *Ftlatcom 5*, launched for DoD, was damaged on entering orbit. DoD orbited 5 satellites for defense objectives, in 6 launch attempts. (See table of 1981 launches in appendix A-3.)

International Activities

In addition to cooperative space programs with other countries in space transportation, communications, applications, and science, U.S. agencies—the Department of State, NASA, NOAA, DoD, AID, and others—prepared for U.S. participation in the U.N. Conference on Exploration and Peaceful Uses of Outer Space (UNISPACE '82), scheduled for August 1982 in Vienna. The conference offers opportunity for

demonstrating U.S. contributions to space science and technology, especially in satellite communications and remote sensing for the developing world—the theme of the conference.

The United States also continued its leading role in the United Nations Committee on the Peaceful Uses of Outer Space. The committee considered draft principles governing direct television broadcasting by satellites, draft principles for remote sensing of the earth, definition of outer space, use of nuclear power sources in space, and use of the geostationary-geosynchronous satellite orbit.

Aeronautics

Operational Systems

Aeronautical development programs, both military and civilian, made advances in 1981 in improving the nation's operational airborne and airway systems.

Airborne Systems. The Department of Defense—responsible for U.S. operational airborne systems—continued to develop new vehicles and improve existing ones.

BOMBER AIRCRAFT. President Reagan's strategic program announced in October 1981 included modernization of the U.S. bomber force, deploying 100 B-1B multirole bombers, with initial operational capability by 1986. The B-1B, an improved variant of the B-1 already prototype-flight-tested, is to be able to carry out tactical and strategic missions of a conventional bomber, launch cruise missiles, and deliver nuclear weapons. Concurrently, a research and development program will seek to develop advanced-technology bombers (ATBs)—now in very early stages of design and concept development—by the early 1990s, to ensure that U.S. bombers will be able to penetrate enemy air defenses into the next century.

TRANSPORT AIRCRAFT. DoD selected the prime contractor in 1981 for full-scale development of the C-17 aircraft, for transporting outsize equipment over intercontinental distances to austere airfields.

HELICOPTERS. The Army neared a production decision on the advanced attack helicopter (AAH), following operational tests in 1981. In modernization of the CH-47 helicopter fleet, two prototype CH-47D medium-lift helicopters had flown some 1740 hours of testing by the end of the year. The Army also had contracted for 337 UH-60A Black Hawk helicopters and accepted delivery of 191. The Air Force planned full-scale development beginning in 1982 of a derivative, the HH-60D, to modernize its combat helicopter fleet.

REMOTELY PILOTED VEHICLE (RPV). The Army scheduled the first flight of its unmanned RPV for mid-1982. Controlled from the ground, the small air vehicle will carry out missions for target acquisition,

laser designation, aerial reconnaissance, and artillery adjustment.

CRUISE MISSILES. The air-launched cruise missile (ALCM) was in concurrent full production, final development, and follow-on operational testing at the end of 1981, with 705 missiles under contract. A 1982 contract for 440 more missiles was being reviewed. Initial operational capability in December 1982 was scheduled for an entire squadron of B-52G aircraft, each equipped with 12 ALCMs, which are designed for greater accuracy, flexible routing, reduced exposure, and saturation of enemy defenses. The first modified B-52G was ready for alert with external ALCMs in September 1981.

Airway Systems. The Department of Transportation's Federal Aviation Administration (FAA)—responsible for the nation's airways—continued development programs to improve the safety of the airways and airports, increase efficiency of air navigation and traffic control, and ensure compatibility of air operations with the environment.

AIR SAFETY. Efforts continued to develop new technology and procedures to enhance the safety of aircraft. For example, FAA, NASA and DoD formed a national task force in 1981 to decide what test facilities are needed for research into aircraft icing, and FAA participated in a report by the NATO Advisory Group for Aerospace Research and Development (AGARD) assessing R&D in helicopter icing.

AIR TRAFFIC CONTROL. Among important activities, FAA evaluated advanced Mode S radar sensors and transponders for gradual replacement of the existing air traffic control radar beacons. A new, airborne traffic-alert and collision-avoidance system (TCAS) was also designed, to operate independently of the existing ATC system.

Aeronautical Research

NASA—the agency primarily responsible for advancing aeronautical technology—and DoD continued R&D programs to maintain U.S. leadership in world air transport and military aeronautics.

Engines. NASA made substantial progress in advancing technology to improve fuel efficiency of commercial, high-bypass-ratio, turbofan engines by as much as 20 percent over present engines. In 1981, full-scale tests of components reached the performance goals.

Aerodynamics. Advancing the use of high-speed computers to predict aerodynamic behavior of aircraft, NASA discovered an algorithm that speeds up computations tenfold in calculating forces and flow fields around wings, airfoils, and bodies. NASA's HiMAT (for highly maneuverable aircraft technology) remotely piloted research vehicle continued experimenting with aeroelastically tailored composite wings for aircraft for the 1990s with major improve-

ment over the turning capability of today's most advanced fighter aircraft.

Structures. The Air Force and the Defense Advanced Research Projects Agency began a program to design, build, and flight-test an experimental forward-swept-wing aircraft using new composite materials to control wing bending, thereby reducing transonic drag and increasing lift at high angles of attack.

NASA focused on developing advanced computer software and hardware for structural analysis. A new prototype system for data-base management—known as RIM, for relational information management—combined many diverse analysis, design, and manufacturing programs into one system using a common data base. RIM has high potential for designing and evaluating new aircraft concepts faster and at significantly lower cost than do present methods using models and wind tunnels. A new class of resins for composite structures was developed in another program. These materials are thermoplastic polyimides that have excellent high-temperature, damage-tolerance, and processability characteristics. Also in 1981, advanced graphite-fiber-reinforced, secondary and medium-primary structural components on the L-1011, DC-10, and B-727 transport aircraft proved savings of up to 25 percent in weight.

Rotor Research. The NASA-Army-Navy XV-15 tilt-rotor research aircraft completed proof-of-concept

demonstration flights, with aircraft performance meeting or exceeding estimates, and concept evaluation began. NASA demonstrated during the year, with an Army OH-6 helicopter, that rotor vibration levels could be dramatically reduced. Two NASA-Army rotor systems research aircraft also continued testing main rotor systems, flying as pure helicopters or in the compound mode with auxiliary thrust engines and variable incidence wings.

Avionics. The Army was to award a contract in 1982 to develop technology for automated, low-level, terrain-following flight. Advanced development continued on the joint, tactical microwave landing system, with hardware flight testing by all three services planned for 1982.

Environmental Research. In 1981, FAA studied effects of aircraft emissions at high altitudes, methods of controlling emissions at low altitudes and on the ground, and ways of handling polychlorinated biphenyl (PCB), a chemical determined to be carcinogenic. The High-Altitude Pollution Program (HAPP) resolved earlier uncertainties in its findings, finally concluding that large-scale operations of supersonic transport fleets would deplete atmospheric ozone, potentially harming the environment—but that subsonic operations would generate ozone, at least partially if not fully offsetting the SST effects. The degree of change in the ozone would depend on the relative sizes of the fleets.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA) plans, directs, and conducts civil research and development in space and aeronautics. Other federal, state, local, and foreign governments and agencies share in these activities. The Department of Defense (DoD) conducts space activities that are solely military; NASA supports DoD with research and test data in aeronautics.

NASA's goals in space are to develop technology to make operations more effective; to enlarge the range of practical applications of space technology and data; and to investigate the earth and its immediate surroundings, the natural bodies in our solar system, and the origins and physical processes of the universe. In aeronautics, NASA seeks to improve aerodynamics, structures, engines, and overall performance of aircraft, to make them more efficient, more compatible with the environment, and safer.

Applications to the Earth

NASA programs to apply space research and technology to national and world needs in 1981 emphasized improving technology for satellite communications, assessing the earth's environment and resources, and exploring the possibilities of processing materials in space.

Communications

Relieving congestion in communications satellite orbits and frequencies, in ways that will support the competitive position of U.S. industry in world markets, continued to be a primary objective of NASA communications research and development.

Advanced Research and Development. Satellite communications using present technology may possibly, in the next decade, saturate the capacity of the geostationary arc viewing North America. NASA therefore conducted a series of traffic forecasts, called for system designs by all the U.S. commercial satellite manufacturers, and pursued "proof-of-concept" component development for advanced satellites in the 30- to 20-gigahertz band. The program will complete

development of several major technologies during 1982, providing some of the basic techniques and components industry needs for commercial satellite systems in the next decade.

Public Service Communications. *ATS 1* and *ATS 3* satellites, launched in 1966 and 1967, continued to provide experimental public service communications in 1981. *ATS 3* was used for emergency communications in the United States, including disaster relief, search and rescue, emergency medical services, and drug law enforcement. *ATS 1* was used in the Pacific basin for similar applications and also for education experiments.

Search and Rescue. The satellite-aided search and rescue program, SARSAT, has as its goal the detection and location, within two to five kilometers, of emergency transmitters on crashed aircraft or vessels in distress. Experiments will be conducted at 121.5 and 243 megahertz, the aeronautical distress frequencies. In addition, experiments will be conducted using a new emergency transmitter operating at 406 MHz, which has been designed to operate in conjunction with a satellite.

SARSAT has generated extraordinary U.S. and international interest. The U.S. team includes, in addition to NASA, the U.S. Coast Guard, the U.S. Air Force, and NOAA. Internationally, the United States is cooperating with Canada and France to fly the instruments on a NOAA spacecraft and with the Soviet Union, which will fly additional COSPAS satellites designed to be interoperable with the SARSAT satellite and ground stations. Norway and perhaps Japan and Great Britain will participate as investigators. NASA planned to launch NOAA-E, the first satellite equipped to detect distress transmitters, in early 1983. The Soviet Union is expected to launch *Cospas 1* nearly simultaneously.

International and National Regulatory Organizations. NASA's technical consultation and support program participated in revising national radio regulations to meet decisions of the 1979 World Administrative Radio Conference. NASA also continued preliminary studies and support toward thin-route narrow-band services, particularly mobile com-

munications, by satellite. The proposed commercial system, augmenting terrestrial land-mobile communications in the 806-MHz band, could meet many public- and private-sector thin-route communication needs.

Data Systems. In-house pilot projects were developing common system approaches to cataloging and managing space applications and related data, developing transportable data-handling software systems for multidisciplinary research, and evolving standards. In 1981, a new effort was begun to modify the growing costs of processing data from the newer high-volume, high-data-rate sensors.

Environmental Observations

Upper Atmosphere. Chemical kinetic and photochemistry data were reevaluated for stratospheric models that predict ozone depletion due to chlorofluorocarbons (CFCs). In 1979, ozone depletion of 15 to 19 percent by the year 2050 was predicted. Most recent models predict only 5 to 9 percent, from CFC-11 and CFC-12 (Freon-11 and -12). With this reevaluation, the expected present ozone depletion is also reduced to about one-third—that is, to 0.5 to 0.7 percent—and is now consistent with the long-term record of observed global ozone concentration.

The ability to measure stratospheric constituents has improved significantly. Instruments on the *Nimbus 7* and *Sage* satellites launched earlier collected nearly global information on ozone, aerosols, and other factors. The data have been validated and archived and are available to the scientific community for analysis. *Sage*, operating past its one-year design life, relayed data into November. At the end of the year a data-processing problem was being assessed. *Nimbus 7* continued to operate at full capacity in its third year, and several years of data will be available for highly accurate determination of stratospheric trends.

Specific experiments in 1981 sought better understanding of the dynamics of and photochemical processes in the stratosphere. An aircraft experiment in the tropics provided data on tropospheric-stratospheric transport mechanisms, particularly transport of water vapor into the stratosphere. Balloons carrying sophisticated lidar and infrared spectrometers measured key stratospheric constituents simultaneously. The measurements are important in validating photochemical models that predict ozone depletion.

Lower Atmosphere. NASA's tropospheric air-quality program made significant advances in 1981 toward understanding the chemistry of the lower atmosphere on regional to global scales. Laboratory and field measurements and modeling all have found that lightning is much less important as a source of nitrogen oxides globally than previously supposed and

that man-made contributions are more important. Evidence was also discovered that methane may be increasing in the lower atmosphere. The source is still a mystery, but the increasing concentration has implications for both atmospheric chemistry and climate, the former because of methane's interactions with free radicals of trace constituents in the troposphere that determine the residence time of many gases in the atmosphere, and the latter because methane is an infrared-active, "greenhouse effect" producer.

NASA research and development also demonstrated that the ultraviolet differential absorption lidar (UV-DIAL) is a powerful tool for mapping regional concentrations of ozone and aerosols as they vary with altitude. The technique also provides data on mixing-layer height, which is a crucial parameter in regional air-quality models. Even though the application of space techniques to tropospheric air-quality observations is still rudimentary, the potential has been demonstrated by using visible-wavelength imagery from geosynchronous satellites to track heavily polluted air masses across large distances.

Global Weather. The one-year observing phase of the Global Weather Experiment, completed in December 1979 in the Global Atmospheric Research Program (GARP), provided an unprecedented set of global observations of the atmosphere. These data were used in model experiments to extend weather prediction, define an operational global observing system, and test understanding of atmospheric dynamics. They were also used to diagnose structure, variability, and mechanisms of atmospheric circulation for that year.

During 1981, addition of global data gathered by satellites to forecast models consistently improved the accuracy of the five-day forecast, as compared to that based on conventional data alone. Use of satellite data also extended the capability for making useful forecasts to one week. Further, global satellite data permitted observations of energetic air masses that move from the tropics into middle latitudes after three to four days. Inclusion of tropical data significantly improved the accuracy of three-day or longer forecasts at middle latitudes. Finally, comparison of forecasts based on satellite data alone with forecasts based on all data, indicated that a satellite-based observing system may someday replace large segments of the conventional, ground-based system.

Flight of visible-infrared, spin-scan-radiometer, atmospheric sounders on the *Goes 4* and *Goes 5* Geostationary Operational Environmental Satellites launched in September 1980 and May 1981 proved that atmospheric temperature and moisture can be mapped from geosynchronous orbit. These capabilities for persistent observation over one area of the globe should improve predictions of weather, especially severe storms. The U.S.-Japanese Cooperative Space Applications Research Program

succeeded in synchronizing the dissimilar weather satellites of the two countries. The resulting stereo observations of clouds over the Pacific Ocean provide measurements of cloud height.

Joint NASA-NOAA-NSF experiments with an aircraft-mounted doppler lidar instrument showed that remote measurements of wind speed and direction can be made in clear air by using laser light scattered by aerosols.

The Centralized Storm Information System at the National Severe Storms Forecast Center in Kansas City demonstrated during 1981 that valuable weather forecasting guidance can be derived from real-time collection and display of satellite and conventional data. Also, weather analysis tools can be developed by using advanced processing techniques such as simulated stereo images.

Oceanic Processes. Preliminary analysis of the data set from *Seasat*, the first satellite dedicated to remote sensing of the ocean surface, was completed in 1981. Despite its brief life—cut short by an electrical failure in October 1978 after 3½ months of operation—*Seasat* provided significant data. The information, now catalogued and archived in the Environmental Data and Information Service of the National Oceanic and Atmospheric Administration, is available for further research in oceanography and meteorology.

Several major research accomplishments were achieved by using these data. Accuracy of the marine geoid was improved from three meters to one meter with measurements by the radar altimeter. Ocean surface characteristics similar to the familiar high- and low-pressure systems displayed on conventional weather maps were determined by the radar altimeter, providing for the first time a surface expression of the variability of ocean currents. The microwave radiometer measured sea surface temperature with an accuracy approaching 1°C. The microwave radar scatterometer made a three-month global record of wind speed and direction at the ocean surface. The synthetic-aperture radar provided very high resolution images of both open and ice-covered ocean, showing distribution of surface wave height and direction.

The technical feasibility of quantitatively measuring ocean chlorophyll pigment and suspended particle concentrations from space (using the *Nimbus 7* coastal-zone color scanner) and from the air (using the airborne oceanographic lidar) was demonstrated and documented in the scientific literature. In combination with a productivity-index model, satellite-derived chlorophyll values were used to measure the rate of change in primary productivity over two weeks for the entire Southern California Bight. Both the standing crop of phytoplankton and the primary productivity of the region decreased to half. Significant changes in global marine primary productivity, due to climate and other causes, and assessment of the rate at which

the marine biosphere takes up carbon dioxide from oxidized fossil fuels can now be documented.

Climate. The stratospheric aerosol measurement (SAM II) satellite experiment, designed to study the climatology of stratospheric aerosols at latitudes above 64°, recently discovered recurrent massive clouds in the arctic and antarctic stratosphere. SAM II was launched aboard the *Nimbus 7* research satellite in October 1978. Data from the first year of operation, now analyzed, include observations of numerous stratospheric clouds at altitudes of 12 to 23 kilometers with peak extinction (of solar radiation) approximately 50 to 100 times that of the normal background level. Twelve such clouds were observed in the arctic stratosphere and 538 in the antarctic, all during local winter. Such clouds have seldom been seen before. Their occurrence appears strongly correlated with low temperature. They are much more prevalent in the antarctic stratosphere during the colder austral winter and persist for up to two months. They could possibly represent a major sink for stratospheric water vapor and be important to the earth's radiation balance.

Several significant results were obtained during 1981 from studies made with the Goddard Laboratory for Atmospheric Sciences (GLAS) climate model. One finding was that the space and time averages for some atmospheric motions can be predicted for a month or longer. Planetary wave motions, calculated from the GLAS model, were found to retain their identities for up to 45 days—about three times longer than the calculated predictability for synoptic scale waves. The finding may have important consequences in medium-range weather forecasting.

Resource Observations

Renewable Resources: AgRISTARS. The interagency Agricultural and Resources Inventory Survey through Aerospace Remote Sensing (AgRISTARS) is developing and testing the utility of remote sensing for providing timely information to the Department of Agriculture. Research emphasizes developing information-extraction techniques for the multispectral scanner and thematic mapper flown on the Landsat satellites. Both accuracy and efficiency of classification techniques for small grains, corn, and soybeans were improved in 1981. Tests in the U.S. corn belt and in the U.S.-Canada small-grains region verified that accurate and efficient preharvest crop forecasts are possible. During 1981, automated procedures that could reduce analyst time to one-sixth that formerly required were developed and tested.

Remote-sensing techniques were developed to produce county-level crop statistics using an existing ground survey for ground truth. Comparison tests of the remote-sensing system against the conventional system showed a variance reduction that averaged more than 50 percent. This technology apparently

would permit estimates of equal accuracy at a lower cost or higher accuracy at the same cost. Other research modeled and measured soil moisture to a depth of five centimeters while accounting for surface roughness and canopy variation. This work used both passive and active microwave instruments.

In 1980, the most comprehensive set of correlated satellite, aircraft-sensor, and ground data yet obtained was developed. During 1981, this data set was augmented and made available to both NASA and non-NASA AgRISTARS-supported investigators for analysis.

Renewable Resources: AR&DA. NASA's Applied Research and Data Analysis program for renewable resources increases understanding of the remote-sensing process and develops and evaluates multispectral and multisensor information-extraction techniques for improved classification and measurement of land cover. In applied research, the emphasis has been to develop simulated thematic mapper and microwave information-extraction techniques. A joint remote-sensing research project was continued with Japan to model snowmelt runoff, using Landsat data, and monitor snowpack properties, using microwave data. These experimental data are being exchanged for use in comparable test sites in the United States and Japan.

In technique testing, the approach is to conduct multiyear joint tests with major users in representative application areas. Two technical outreach conferences were held in 1981 as the culmination of successful testing of techniques in developing the forest resources information system and a wildlife vegetation resource inventory system. Testing was completed on an automated cotton-acreage inventory system. Technique testing is continuing in irrigated lands assessment for water management, monitoring insect defoliation of hardwood forests, crop classification employing soils data, and digital mapping of irrigated cropland.

Nonrenewable Resources. During 1981, work was completed on the NASA-Geosat Test Case Project, a joint research endeavor with private industry to evaluate remote-sensing techniques for geologic mapping. The project collected and analyzed remote-sensing data over a series of experimental sites containing known deposits of copper, uranium, oil, and gas. It was judged highly successful by both NASA and the industrial members of the Geosat Committee. Results indicated that analysis of remote-sensing measurements can yield geological information not commonly obtained by conventional field mapping. In particular, the project defined the potential utility of thematic-mapper-scanner data for mapping certain clays commonly associated with specific mineral deposits. Several companies are upgrading their in-house remote-sensing capabilities in anticipation of the launch of Landsat-D in 1982.

Parallel research during 1981 concentrated on geological applications of radar remote-sensing techniques. New image processing methods were developed to co-register and merge radar data obtained by *Seasat* and multispectral scanner data acquired by Landsat satellites. Preliminary results indicate that information on kinds of rock derived from the combined data is significantly more accurate than that from either set alone. Research is also under way to develop new methods of measuring and using textural information in remote-sensing imagery, specifically radar imagery. Studies of *Seasat* radar imagery acquired over the Patrick Draw oil field in Wyoming showed that textural parameters can identify boundaries between rock units that cannot be easily separated by their spectral signatures.

The *Magsat* satellite made the first global survey of the earth's vector magnetic field from November 1979 to June 1980. Data reduction was completed in August 1981, and the products were distributed to *Magsat* principal investigators. The accuracy of the final data exceeded original mission goals by approximately 20 percent. *Magsat* data were used to develop a global model of the earth's magnetic field that was recently adopted as a standard worldwide reference field by the International Association for Geomagnetism and Aeronomy. Preliminary maps of crustal magnetic-field strength were also produced. These maps are used in developing regional models of crustal structure and composition for evaluation of nonrenewable resources.

On its second test flight, in November, the Space Shuttle carried the first science and applications payload into orbit, with two experiments directly related to geological mapping. Shuttle imaging radar A (SIR-A) data delineate faults and other geological features. SIR-A imagery will be directly compared with *Seasat* radar data to determine the radar viewing geometry best suited to geological mapping. The other experiment flown was the Shuttle multispectral infrared radiometer (SMIRR). Data provided by this instrument are being used to identify different kinds of rock by the reflectances in the infrared region of the spectrum. This information will be correlated with ground data to determine the effectiveness of the SMIRR spectral bands. Analysis will continue through 1982 and will aid in selecting spectral bands for future spaceborne systems.

Landsat Operations. *Landsat 2* and *3* continued to provide worldwide multispectral imagery for applications in agriculture, hydrology, coastal zone management, land use, and mineral and petroleum exploration. The data are used by both commercial and local government agencies and by foreign countries.

Development of Landsat-D progressed toward a scheduled summer 1982 launch. The Landsat-D thematic mapper will provide multispectral imagery with extended spectral range, improved spectral and

spatial resolution, and improved radiometric accuracy. To familiarize potential users, simulated thematic mapper data have been acquired from aircraft platforms in vegetated and nonvegetated test sites in urban, rural, coastal, forest, and degraded land areas.

Geodynamics. NASA's geodynamics program contributes to understanding the solid earth, in particular the long-term crustal processes associated with natural hazards and resources, and the structure and internal composition of the earth. It also facilitates new geodynamics measurement capabilities requiring precise position determination. The program includes research in modeling of crustal processes, earth rotational dynamics, and the geopotential field. The principal space techniques available for precise measurements of crustal motion and deformation, polar motion, and earth rotation are very-long-baseline interferometry (VLBI)—using signals from extragalactic radio sources or from satellites—and laser ranging to the moon and to man-made satellites such as *Lageos*.

The Crustal Dynamics Project was begun in 1981, and NASA, U.S. Geological Survey, National Science Foundation, Defense Mapping Agency, and NOAA's National Geodetic Survey signed an agreement establishing a coordinated federal program for applying space technology to geodynamics. The transportable laser-ranging station, designed and built by the University of Texas at Austin, was completed and deployed to the Jet Propulsion Laboratory for baseline comparisons with VLBI. The station will facilitate the measurement of crustal deformation in the western U.S. Fifty-nine independent baselines were measured in 1980 using both laser ranging and VLBI, besides those measured using European stations, and the Crustal Dynamics Project added 124 by the end of 1981. Comparison of determinations at observatory sites in New England, Texas, and California showed agreement between VLBI and laser ranging to better than five centimeters. Analysis of laser-ranging observations at Quincy and Otay Mountain, California—continuing measurements acquired by the San Andreas Fault experiment since 1972—showed good agreement with past measurements, strengthening the conclusion that the distance between these two sites is decreasing by about eight centimeters a year. The decrease is consistent with contemporary theory of tectonic plate movement as to direction, but larger than predicted.

The International Council of Scientific Unions approved a request from the International Union of Geodesy and Geophysics and the International Union of Geological Sciences to establish a successor project to the highly successful International Geodynamics Project of 1971–1980. The new International Lithosphere Project will be conducted through 1989 by the Inter-Union Commission on the Lithosphere.

Two of its five scientific objectives require measurements from space of plate movement and deformation. The International Association of Geodesy established a Commission on International Coordination of Space Techniques for Geodesy and Geodynamics.

A panel, established under the auspices of the Satellite Geodesy Applications Board, developed a plan for joint-agency participation in the planned Gravity Satellite mission. A brassboard model was completed of the Gravsat satellite-to-satellite tracking system, required to make gravity measurements and for simulation of the drag-free system. Recent tests confirmed that the required tracking accuracies are feasible. Computer simulations show that the Gravsat mission as configured can improve the accuracy of gravity field models by two to three orders of magnitude.

Materials Processing in Space

NASA continued to investigate the feasibility and benefits of materials processing in low gravity. The agency seeks to improve processing methods, to identify materials of technological interest, and to enter arrangements with companies that would promote the early commercialization of space processing.

The processing of materials in the fluid state is often tied to the influences of gravity. Convection, sedimentation, buoyancy, body forces, and the need for a container are among the consequences of gravity that may aid or hinder terrestrial processing of materials. The research program establishing a theoretical and experimental data base on the role of gravity emphasized containerless technology and containerless science during 1981. Levitation and positioning devices, which will be necessary to achieve long processing times in spacecraft, are being developed that use acoustic, electromagnetic, or electrostatic forces. Acoustic devices now available can, in earth's gravity, levitate lightweight samples that are as hot as 500°C, while simultaneously spinning or oscillating them—steps that are important in many processing procedures. Containerless science investigated solidification, supercooling (below the normal freezing point), and glass formation. Using a 30-meter drop tube to achieve 2.3 seconds of containerless, low-gravity processing time, for example, the supercooling of several metals and alloys by as much as 500° to 700°C was found to be accompanied by changes in superconducting properties.

Ground-based research examined crystal growth, solidification, chemical and fluid processes, biological separations, combustion science, and cloud physics in 1981. Experiments on board an aircraft during 30-second low-gravity parabolas showed that the casting structure for alloys solidified in low gravity indeed differs from that obtained on the ground. Ex-

periments seek to determine what changes will occur with low-gravity processing in the structure, properties, and quality of a wide range of technological materials, including semiconductor crystals (for infrared and nuclear detection), magnetic composites, new glasses, and laser fusion target shells. Two sounding rockets launched in 1980 and one in 1981 provided up to five minutes of low-gravity experimentation in these areas.

The first Space Shuttle flight opportunity for materials processing will be in March 1982, with a mid-deck experiment on the formation of monodisperse (uniformly sized) latex spheres. The materials experiment assembly, housing three experiments, will be flown in late 1982 and provide the first long-term low-gravity experimentation for new glass formation, vapor crystal growth, and immiscible metal solidification.

Commercial activities increased in 1980 and 1981. The first two joint-endeavor agreements with NASA were signed—the first one by McDonnell Douglas Corporation for the separation in space of pharmaceuticals for treating human and animal diseases. A joint-endeavor agreement reduces investment risk and is intended to stimulate the commercialization of space processing; NASA provides free transportation and the company receives limited exclusivity and data rights during precommercialization trials. The first of six mid-deck experiments under the agreement will be carried out in mid-1982, with pilot-plant testing expected in 1985-1986. The second joint-endeavor agreement was signed with GTI Corporation for low-gravity solidification services, and NASA was reviewing a third proposal, for production of semiconductor crystals.

The first technical exchange agreement was signed in mid-1981, with the John Deere Corporation to study convection effects on cast iron structure. Under this agreement, an industry not yet ready to commit itself to a joint endeavor can investigate low-gravity processing by sharing information and ground-based experimental facilities. Two additional technical exchange agreements, directed toward catalyst formation and electroplating studies, were also signed. No funds are exchanged between NASA and the private partner in any of these cooperative activities.

Technology Transfer

NASA's technology transfer program assists federal, state, and local governments and private sectors of the economy to use remote-sensing technology emerging from NASA's R&D program and provides guidance to future R&D efforts.

Jointly conducted applications projects were completed in 1981 with the National Park Service and with the Pacific Northwest Regional Commission. In pilot areas of Olympic and Shenandoah National Parks and

Death Valley National Monument, Park Service personnel tested the use of Landsat land-cover data in forest-fire management, in wildlife-habitat assessment, in forest and vegetation mapping, and as a source for other land-cover information required for park management. Sixteen states have acquired equipment for analyzing Landsat data and comparable capabilities are under development in another eight to ten states.

Private sector activities continued in 1981 with Pacific Gas and Electric Company in California. NASA's Ames Research Center began work in 1980 on a joint application project with PG&E to use Landsat data, integrated into a geobased information system, to map power-line corridors, project energy demand, assess environmental impacts, and identify future facility sites.

In the technology utilization program, NASA completed several projects in 1981 applying aerospace technology to medical uses, facilities for the handicapped, agricultural productivity, low-cost systems for processing waste water, and archaeology. An automatic implantable defibrillator incorporating several aspects of NASA-derived technologies may aid many of the more than one million persons who suffer heart attacks each year. In 1981, 28 defibrillators were implanted in patients under the clinical evaluation program sponsored by the National Institutes of Health. The Intec Corporation of Pittsburgh manufactures the defibrillators.

Science

Space science aims at an understanding of the origin and continuing evolution of the cosmos, the origin and evolution of the solar system, the origin and distribution of life in the universe, and the dynamic processes that shape the terrestrial environment. Space science also uses space technology and the space environment to further knowledge in medicine and biology.

Study of the Sun and Its Earth Effects

In its solar-terrestrial program, NASA carries investigations above the atmosphere to study the sun as a star and its effects on space near the earth. By observing the surface of the sun and its corona, by following the flow of particles from the solar wind, and by measuring the effect of the earth's electric and magnetic fields on trapped particles, NASA seeks to understand the solar-terrestrial system and ultimately to predict conditions in the near-space environment through which all spacecraft must pass and at the earth.

Solar Maximum Mission. The SMM spacecraft launched early in 1980 was placed in a spinning mode because of the partial failure of its pointing system in

November 1980. Three of the seven experiments were unaffected by this problem and continued to return high-quality data. At the end of 1981, plans were being developed for a possible repair of the pointing system in orbit, to reestablish the full capability for studying solar flares and other solar activity.

Explorers. Two Explorer missions in 1981 began investigating the transport of matter and energy into and out of the magnetosphere. On 3 August 1981, the two spacecraft of the Dynamics Explorer (DE) mission were launched on a single Delta launch vehicle—one into a high-apogee orbit, the other into a low-apogee orbit. The mission is studying the interactions between the magnetosphere and the ionosphere, particularly the exchange of energy between these two regions, the acceleration of particles, and the processes that lead to auroras.

The Solar Mesosphere Explorer *SME* was launched 6 October from the Western Space and Missile Center to supply specific knowledge on the nature and magnitude of changes in the mesospheric ozone densities caused by changes in solar ultraviolet flux. A basic mission lifetime of one year was planned.

The three spacecraft launched in 1978 in the International Sun-Earth Explorer (ISEE) mission continued to increase our understanding of the interactions between the fluctuating solar wind and the outer limits of the magnetosphere that controls the earth's near-space environment.

The Active Magnetospheric Particle Tracer Explorer (AMPTE) project was begun in 1981 as a dual spacecraft project in cooperation with the Federal Republic of Germany. The *Ion Release Module* will eject chemicals at very high altitudes, first sunward and outside the magnetosphere and later at the flanks of the magnetosphere and deep in the magnetospheric tail. When the chemicals are ejected, the *Charge Composition Explorer* will attempt to detect the released particles from inside the magnetosphere. Scientists will then trace the motion of the ions and investigate their energization.

International Solar Polar Mission. During 1981, the U.S. spacecraft in the planned two-spacecraft International Solar Polar Mission (ISPM) was deleted because of the need to maintain priority programs in a restrained spending environment. The European Space Agency spacecraft, with its complement of European and U.S. experiments, is scheduled to visit hitherto unexplored parts of space out of the plane of the planetary orbits in the late 1980s.

Suborbital Observations. Sounding rockets and balloons continued to serve as important platforms for the development and flight test of new instruments while investigating phenomena just above the atmosphere. As part of a program to study electrodynamic interactions with the ionosphere, the first successful coordinated study of thunderstorms using an aircraft, sounding rockets, and balloons was conducted in

1981. Three sounding rocket payloads at altitudes of 150, 90, and 60 kilometers measured the electric fields over a thunderstorm at the same time as the fields were measured by a balloon at 32 kilometers. Weather radar mapped the thunderstorm region.

Study of the Planets

In 1981, another major advance in the U.S. exploration of the solar system was achieved by *Voyager 2*'s nearly perfect encounter with Saturn. The program also acquired significant new information at Venus and Mars and in interplanetary space. The data pertain to many disciplines, including basic plasma physics, climatology, and planetary volcanism.

Voyager 1 and 2. The very successful *Voyager* spacecraft, launched in 1977, continue their investigations of the outer regions of the solar system. After its historic encounter with Saturn in November 1980, *Voyager 1* was deflected out of the ecliptic plane on a trajectory headed toward the solar apex—the direction the sun is moving in the galaxy. This spacecraft is to be tracked as its instruments investigate the outer solar system environment and interactions of the solar wind with interstellar material.

Voyager 2's encounter with Saturn and its satellites in August 1981 obtained new scientific data about this giant planet, its rings, and its satellites. The spacecraft's trajectory permitted images to be taken that could not be obtained by the earlier passage of *Voyager 1*. New information was obtained on the generation and circulation of storms in Saturn's atmosphere. Observing the rings as they occulted a bright star, *Voyager 2* found that gaps between ringlets are far from empty. Instead of being hundreds of individual rings, it now appears that there are just a few distinct rings around Saturn with bands of increased density that appear as ringlets. One new theory is that the ringlets are actually tightly wound, spiral density waves stimulated by resonances with the outer large satellites. Images of the rings and radio science data also show variations in the distribution of particle sizes and possible variations in composition.

Among the satellites of Saturn, Hyperion was revealed to be an irregularly shaped satellite with numerous impact craters, probably a fragment of something larger that broke up. Images of Iapetus show promise of explaining the great contrast between the dark and bright icy sides of this satellite. High-resolution images of Tethys and Enceladus show that their surfaces have undergone great changes. Part of the surface of Tethys is clearly less cratered than other parts, like those of Rhea and Dione observed by *Voyager 1*. New images of Tethys show that its large trench girdles nearly three-fourths of the body. At least five distinct geological surfaces were observed on Enceladus. Saturn's outermost satellite, Phoebe, which orbits in the opposite direction of the other

satellites, was observed to be spherical. The shape was a surprise, since it had been thought to be a captured fragment rather than an accretionary object. Its origin remains unsolved.

Analysis of the Saturn data from both Voyagers is just beginning. Numerous new puzzles have been identified, and many accepted theories of planetary formation must be modified.

Voyager 2 was deflected by Saturn onto a trajectory toward Uranus, as planned. Late in September, a propulsive maneuver ensured it will reach the vicinity of Uranus in January 1986. If it can continue to operate for another five years, we should learn much about this unusual, tilted, gaseous planet with rings and five satellites. After that, *Voyager 2* possibly can be directed onward to Neptune, 19 times as far from the sun as Earth is. Because of the great distances of Uranus and Neptune from Earth, little is known about these planets, and changes in our present knowledge comparable to that resulting from the Saturn flyby can be expected.

Viking. Viking lander 1 has continued active scientific investigations on the surface of Mars for almost six years. The lander is programmed to allow periodic interrogations to retrieve imaging, meteorology, radio science, and engineering data until December 1994. Of the transmissions during the first year in a monitoring mission mode, 89 percent have produced excellent scientific information. The data are currently acquired at low cost. Considerable analysis of data also continues from the period when four Vikings were operational.

In a ceremony on 7 January 1981, the NASA administrator accepted the first contributions from the Viking Fund. The fund was established by the San Francisco Chapter of the American Astronautical Society to enable private citizens to contribute to continued operation of Viking and analysis of data. During the ceremony, the administrator designated Viking lander 1 the *Thomas A. Mutch Memorial Station (MMS)* in memory of the Viking imaging team leader and later NASA associate administrator for space science. Dr. Mutch was injured and then disappeared during a mountain-climbing expedition in the Himalayas in 1980.

Pioneer-Venus. During 1981, Pioneer orbiter operations continued into the fourth Venusian year, providing valuable new scientific data on the time-variable atmosphere of Venus. Data acquired daily permitted study of previously inaccessible areas and extended temporal coverage.

Of particular importance are measurements of the solar wind and its interaction with the ionosphere and upper atmosphere of Venus. Because of natural variations in the spacecraft's orbit, new regions of the fore-shock, bow shock, magnetosheath, ionopause, and ionosphere were sampled each day, contributing toward a complete spatial "map" of these features.

Several more years of data gathering and analysis will be required to understand fully the complex spatial and temporal variations of these interactions. Ultraviolet images collected daily revealed much about the lower levels of the Venusian atmosphere, including the time-variable features in the cloud deck. These data are vital to understand the global circulation pattern.

In 1986, the altitude of the spacecraft periapsis (lowest point of the orbit) will start decreasing. By 1991, the latitude change will permit the radar instrument to map portions of the southern hemisphere surface not previously visible. Thus, natural gravitational forces will permit new segments of the planet's geography to become known, which otherwise would have required an additional mission to achieve.

The *Pioneer-Venus* orbiter is expected to operate until 1992, when gravitational forces will pull it into the lower atmosphere, where it will burn up.

Pioneer 10 and 11. Both spacecraft continued their journeys through the outer reaches of our solar system during 1981. On 26 July, *Pioneer 10* was 25 astronomical units (3.7 billion km) from the sun. The major technical achievement is also significant for discovery that the boundary of the heliopause, where the solar wind effectively stops and the interstellar medium begins, is farther from our sun than had been predicted. By the end of 1981, *Pioneer 10* was at 26.2 AU (3.9 billion km), closing on the orbit of Neptune. *Pioneer 11*, moving out of the solar system in the opposite direction, by the end of 1981 reached 11.25 AU (1.7 billion km) from the sun. Both spacecraft continued to measure solar and galactic phenomena in interplanetary space. A statistical study of measurements from 1 to 20 AU showed that the solar wind moves in a radial direction with a surprisingly constant velocity. Its temperature is consistently greater than predicted, indicating an additional heating mechanism in space. The nature of the mechanism was being investigated by several scientific groups.

Data reduction continued on the vast amount of scientific information acquired in previous years during Jupiter and Saturn encounters. New findings include a cross-flow electrical current on Jupiter's front-side magnetosphere. Magnetic field measurements at Saturn indicate a simple spin-axis-aligned dipole with a one-tenth Saturn radius offset, plus a ring current. And radiation intensity profiles measured in Saturn's inner magnetosphere are not consistent with conventional theory. For this last phenomenon, alternate sources of radiation were being investigated.

Both spacecraft were expected to be tracked and interrogated for 8 to 10 more years, until spacecraft voltage is insufficient to power communications.

Galileo. Designed to study the Jovian system in great detail, the *Galileo* mission was in the development stage during 1981. An orbiter and probe were scheduled to be launched in the mid-1980s and to arrive at

Jupiter in the late 1980s. Plans were for the orbiter to send back imaging, remote-sensing, and magnetospheric information about the planet and its satellites for 20 months, with flybys of the satellites as close as 200 km. On arrival at Jupiter, the probe would descend into the atmosphere and make detailed measurements of chemical and physical properties to a pressure equivalent to 10 Earth atmospheres.

Galileo completed development hardware testing in 1981 and passed the critical design review in November. All subsystem designs for the orbiter were complete, with some flight hardware in production, including the retropropulsion module contributed by the Federal Republic of Germany. Major contracts were renegotiated according to the new launch schedule.

Venus Orbiting Imaging Radar (VOIR). Plans for a mission to map the surface of Venus in mid- to late 1980s with a synthetic-aperture radar instrument on a spacecraft in low circular orbit were being considered. Venus is a twin planet to Earth, but its evolutionary history is largely unknown because its cloud-shrouded surface has never been observed. Scientific measurements from the proposed mission would provide accurate altimetry (topographic readings) for the planet and would map 90 percent of it by radar images at very high spatial resolution.

Research and Analysis. The research and analysis program continued to study data from *Viking 1* and 2 and *Pioneer-Venus* missions. Of particular note was the finding that interactions between the Martian atmosphere and surface, implied by Viking orbiter and lander measurements and Earth-based radar returns, indicate the presence of water on Mars in the form of ground ice. Volcanic surfaces also have been classified, and estimates are that, because of the long igneous history of Mars, 1 to 10 percent of the surface could be granite. In other work, a theoretical study found that Venus may be just enough smaller than Earth that a solid metallic core cannot develop in its molten interior. Lack of an inner core could explain why Venus has no intrinsic magnetic field.

Collection of extraterrestrial particles, thought to be dust particles from comets, was extended significantly. A new collection system was tested on high-flying aircraft, sampling a greater column of dust than in all previous attempts combined and returning a generous supply of particles for analysis. Another source of extraterrestrial materials, the Antarctic Meteorite Collecting Expedition, returned with 103 meteorites. Study of a small iron meteorite collected on an earlier expedition revealed it to contain small diamond crystals. These are thought to have been formed by impact with another meteorite. Other meteorites with unusual intergrowths of graphite and magnetite contain isotopes that indicate they are ancient, perhaps primordial. Studies of another, rare group of meteorites known as shergottites reveal them to be of

such a young age that volcanism on Mars has been suggested as a possible origin.

The new Infrared Telescope Facility in Hawaii obtained spectral data on a satellite of Uranus and searched for a Neptunian ring system. It also obtained spectral evidence of propane on Titan and water on Iapetus, both Saturnian satellites, adding validity to the Voyager mission results. Measurements made by another telescope facility revealed methane in the atmosphere of Pluto.

An International Halley Watch (IHW) has been established to encourage and coordinate scientific observations of Halley's Comet throughout its 1985-1986 appearance. An IHW Steering Committee, an international group, has been established. All data, including that from the cometary spacecraft as well as from astronomical observations, will be assembled and archived under IHW direction.

Studies of the Universe

The objective of astrophysics research at NASA is to investigate, from orbital and suborbital missions, the nature of the universe. In 1981, major advances in our understanding came from the High Energy Astronomy Observatory and the International Ultraviolet Explorer missions, and significant progress was made on developing missions to be launched starting in 1982.

High Energy Astronomy Observatory. Operations for the last two HEAO satellites ended in 1981. The highly successful series exceeded all expectations. The supply of control gas on *HEAO 2*, launched in November 1978, was depleted in April 1981. It carried the largest focusing x-ray telescope ever flown, and its results have precipitated important and still incomplete revisions in almost every area of high-energy astrophysics.

The third spacecraft in the HEAO series was launched in September 1979. Its gamma-ray spectroscopy experiment depleted its supply of cryogenic coolant in May 1980, but its cosmic-ray experiments continued to gather data until the summer of 1981. One of the major results from *Heao 3* was to confirm the presence of gamma-ray emission at energies characteristic of the annihilation of anti-electrons from a direction of the galactic center. A decrease was observed between the fall 1979 and spring 1980 scans of the source, ruling out diffuse sources of anti-electrons and suggesting that the emission may be from a massive black hole at the center of our galaxy.

Space Telescope. The *Space Telescope*, a cooperative project with the European Space Agency and scheduled for launch by the Space Shuttle in the first half of 1985, will greatly improve our ability to observe the universe at optical and near-ultraviolet wavelengths. During 1981, the 2.4-meter primary mirror was polished and coated. The secondary mirror also has been polished and coated; and the main ring,

focal plane structure, and metering truss structure have been assembled.

Gamma Ray Observatory. *GRO* will make the first comprehensive survey of the sky over the entire spectrum of gamma-ray energies. Four scientific instruments, each more than 10 times more sensitive than any similar instruments previously flown, were selected in 1981 for flight on *GRO*: a high-energy gamma-ray telescope, a gamma-ray burst locator and spectrometer, a medium-energy gamma-ray telescope that operates on the principles of Compton scattering, and a broadband gamma-ray spectrometer.

Explorers. The International Ultraviolet Explorer *IUE*, launched in 1978 into a geosynchronous orbit, was still operating well at the end of 1981. Another international Explorer, the Infrared Astronomical Satellite *Iras*, was in preparation as the first satellite designed to study the cold-infrared universe. In 1981, the telescope system was integrated with the *Iras* spacecraft in the Netherlands and was returned to the United States for final testing. The cooperative project with the Netherlands and the United Kingdom is scheduled to place the "first of its kind," cryogenically cooled telescope system in orbit in 1983.

Suborbital Observations. The development and flight-testing of new instruments from sounding rockets, balloons, and high-flying aircraft continued to bring discoveries about the universe that surrounds us. In 1981, instruments aboard the *Kuiper Airborne Observatory* detected, for the first time, radiation at far-infrared wavelengths from a quasar, 3C345. Measurement shows that the bulk of the radiation from the quasar is being emitted at infrared wavelengths. From a NASA balloon, a microwave radiometer observed the first intrinsic distortions, a quadrupole anisotropy, in the cosmic 3-kelvin (-270°C) background radiation thought to be left from the "big bang" at the formation of the universe.

Life Sciences

The life sciences flight and ground-based research programs focus on understanding the effects of the space environment on living organisms, providing medical selection standards and health maintenance for astronauts. Programs develop life support technology and seek to understand the origin and distribution of life in the universe.

Operational Medicine. Preventive medicine for astronauts, including medical support to the first Space Shuttle flight, was the highlight of operational medicine activities in 1981. Medical concepts and systems for the mature STS era were being developed and tested.

Gravity forces experienced by astronauts returning in the Shuttle are quite different in magnitude and direction (relative to the astronaut's position) from previous U.S. and USSR manned flights. This change

may increase postflight orthostatic intolerance (tendency toward fainting) during the early phases of Shuttle landing operations. Men and women 25 to 65 years old were studied in simulated weightlessness and different Shuttle reentry profiles to determine the variability of individual cardiovascular response. Although older males tended to tolerate centrifuge runs following bedrest better than females or younger males, most subjects experienced orthostatic intolerance of 2 g or higher. NASA's antigravity suit offered good protection to all the tested subjects. Since fluid loss in flight contributes to the postflight tendency to faint, a countermeasure of giving drinking fluids and applying negative pressure to the legs was being tested. A lightweight, stowable, lower-body negative-pressure suit was devised.

Biomedical Research. Ground-based researched continued close scrutiny of cardiovascular deconditioning and motion sickness through simulating symptoms met in spaceflight. Short-term, head-down, bedrest studies, designed to decondition the body, have been followed by procedures to provoke illness and then by countermeasures including drugs and special exercises.

Motion sickness has been induced in parabolic flight in aircraft and by motion-producing environments on the ground. New drugs against the resulting nausea and preventive biofeedback techniques have been tested. Researchers continued to trace the complex neural pathways that mediate the development of motion sickness in animals.

Workers concerned with the bone softening observed in long spaceflights have been somewhat encouraged by recent reports from Soviet investigations. The US/USSR Joint Working Group in Space Biology and Medicine learned that cosmonauts completing 175- and 185-day flights lost less bone mass than predicted. U.S. and USSR investigations were seeking to verify these findings with more refined measurement procedures.

Space Biology. Investigations of the combined influence of gravity and light on direction-finding and tropistic response (movement) in plants have indicated a commonality and interaction of the response mechanisms. Experiments with monochromatic light permitted separation and dissection of the mechanisms dealing with plant rhythmic motions and growth—gravitropism and phototropism—and to show how they are related and how they differ. Recent research indicated light and gravity can control plant growth through a common calcium-dependent biochemical reaction. This research should lead to methods of cultivating plants in a gravity-free environment.

Exobiology. Recent discoveries greatly expanded our models for the origin, evolution, and distribution of life and life-related molecules on Earth and throughout the universe. The Voyager observations at Titan confirmed the presence of small organic molecules, some of them critical for the synthesis of

other molecules essential for life. These findings provide additional evidence that the chemistry preceding life is widely distributed beyond Earth. Scientists have synthesized small catalysts (proto-enzymes) under conditions believed to have been prevalent on primitive Earth. This synthesis would have been a necessary step in the development of biological systems. Samples of the oldest rocks on Earth have been found to contain well-preserved microfossils of primitive bacteria, pushing back the time for the origin of life on Earth to a point earlier than 3.5 billion years ago. These and other studies provide further evidence that chemical evolution and the origin of life parallel the development and evolution of planetary systems.

Biological Systems Research. Research on regenerative life support systems in 1981 identified a technique that can be used to purify waste water in a manned spacecraft, without requiring distillation or expendable chemicals. Based on the principle of oxidation in water at high temperatures and pressures, the process works on human wastes as well as wash water; its products are sterile water, carbon dioxide, nitrogen, and precipitated mineral salts. Progress has also been made in the development of spacesuits that can operate with higher internal pressures and in research on methods for regenerating food, air, and water in closed life support systems.

Flight Programs. Life sciences flight experiments in Spacelab will provide objective, quantifiable data to answer many questions raised in the Skylab program. The most immediate problem is space motion sickness, which affected about half of the astronauts during the first one to four days of flight. The STS crew and payload scientists could, if similarly affected, lose a substantial amount of productive time. Additional problems concern fluid and electrolyte balance, sensory deprivation, diurnal rhythm changes, cardiovascular deconditioning, circulation impairment, and muscle atrophy.

During 1981, panels of non-NASA scientists evaluated some 90 proposals for life-science experiments to fly in Spacelab, while NASA analyzed engineering, costs, and mission compatibility. The proposals were found to be scientifically and technically sound, and the majority were funded for further definition. After the number was narrowed to 30 or 40, a payload was selected in September for a mission dedicated to life sciences, planned for Spacelab 4. Work continued, meanwhile, on experiment hardware for Spacelab 1, 2, and 3.

Spacelab Flight Program

The operational phase of the Spacelab flight program began in 1981 with the launch of the first space science and applications payload, OSTA 1, on the second flight of the Space Shuttle, STS 2, in November.

OSTA 1 was the first to use a Spacelab pallet, an engineering model of equipment developed by the European Space Agency to accommodate payloads and instruments that stay with the Shuttle during flight.

OSTA 1 gathered data on renewable and nonrenewable earth resources, on the oceans, and on technology for future instrument development. In addition, the mission demonstrated the capability of the Space Shuttle to serve as a platform for scientific investigation. The next Shuttle flight, STS 3 scheduled for spring 1982, will carry OSS 1, which has objectives in physics, astronomy, and space technology. OSS 1 completed payload integration at Goddard Space Flight Center and was shipped to Kennedy Space Center in September 1981 for integration into the Space Shuttle. Final preparations for launch were proceeding on schedule.

Test flights of Spacelab, developed by the European Space Agency, will carry scientific payloads. Spacelab mission 1 (SL 1), intended to test the pressurized module configuration, was being readied in 1981 for late 1983 launch. The scientific portion of the mission is multidisciplinary and a cooperative venture between NASA and ESA. The ESA-provided instruments were being delivered to an integration site in Europe for final tests before delivery to Kennedy. Some NASA-sponsored investigations had been delivered, and the rest were completing environmental testing. The instruments will be integrated with the first Spacelab flight unit, which was delivered to Kennedy in December 1981.

SL 2 will test the pallet-only configuration of Spacelab while conducting investigations in physics and astronomy. Most of the instruments had completed critical design reviews and were being fabricated. Acceptance tests began in late summer 1981 and were to extend through 1982.

The first operational Spacelab mission, SL 3, will conduct experiments in materials processing, life sciences, and technology research requiring very low gravity. Critical design reviews of all experiments had been completed and fabrication was under way. Development of two instruments, the atmospheric trace molecule spectroscopy instrument and the geophysical fluid-flow cell, was completed.

OSTA 2, a cooperative venture in materials processing with the Federal Republic of Germany, was proceeding on schedule for launch in the Shuttle in late 1982. Fabrication of the experiment carrier was completed during the third quarter of 1981, critical design reviews were held for the NASA and German experiments, and the cargo integration review for the STS 5 launch was held during the fourth quarter. A demonstration of lightweight solar-array technology and solar-cell calibration techniques was planned for the Office of Aeronautics and Space Technology mission OAST 1, scheduled for 1983. The initial design

evaluation was completed, allowing detailed engineering and design to proceed. The monodisperse latex reactor (MLR), a suitcase-size payload for materials processing research on board the Shuttle, was delivered to Kennedy in November for integration into the orbiter. It was to be carried aloft on four Shuttle missions, the first scheduled for March 1982.

Studies were completed for OSTA 3, a follow-up mission to OSTA 1 for earth observations in mid-1984. A cluster of three telescopes was approved for flight on OSS 3 to make astronomical observations in the ultraviolet. Mission definition studies for OSS 3 were completed in 1981, and development of the telescopes was begun. Studies were under way to assess the possibility of using the same instruments for synoptic observations of Halley's Comet from low earth orbit in 1985 and 1986. OSS 2, planned for x-ray and cosmic-ray astronomy studies, has been deferred until later. Mission feasibility studies were completed and definition activities begun for a 1985 launch of Spacelab 4, the first dedicated life science laboratory on the Shuttle.

The new payload processing facility at Kennedy Space Center was activated in 1981 to process OSTA 1 and future payloads.

Procurement activities began for the solar optical telescope (SOT), in preparation for a first flight on the Shuttle in 1987. This major facility-class instrument is planned to provide unparalleled capability for high-resolution solar imagery and spectroscopy well into the 1990s. Focal-plane instruments for SOT were selected and detailed system definition is proceeding.

Concept studies for the Shuttle infrared telescope facility (SIRTF) were completed. Planned for first flight in 1988, SIRTF will be an enormous gain in sensitivity and will permit the first detailed studies of many faint infrared sources. The engineering model of the attitude gimbal system (AGS), for precision pointing of Spacelab instruments at celestial and terrestrial objects, was completed and being tested.

The concept of a *Space Platform* to support space science and applications investigations received wide acceptance in prospective user communities and was being studied further. An extension of the "Spacelab approach" for longer duration missions, the proposed Shuttle-tended facility in space would support a variety of temporary payloads in succession. The Shuttle would attach payloads to the platform to operate for six months to a year and then retrieve them.

Space Transportation

Space Shuttle

The Space Shuttle system, based on the first reusable earth-to-orbit vehicle, is designed to meet the needs of NASA, DoD, and other domestic and inter-

national users of space. Providing efficient, economical access to space with increased mission flexibility will permit new and improved space operations while costing less than comparable expendable launch systems.

The Space Shuttle made its first two orbital flights in 1981, the first in April and the second in November, each manned by two astronauts. All major objectives were met on both test flights. After the first two-day flight, the orbiter *Columbia* was refurbished and launched again, carrying the first experimental payload as well as the remote manipulator system (RMS) contributed by Canada. The second flight also lasted just over two days. Two more test flights will be launched before the Shuttle becomes operational late in 1982.

Orbiter. All systems of the Space Shuttle orbiter, which returns from orbit to land like an aircraft, operated satisfactorily and no major problems were reported during its first mission. Minor damage to the thermal protection tiles and difficulties with two auxiliary power unit heaters and a flight-test instrumentation recorder did not affect the orbiter's overall excellent performance.

Following landing and deservicing at Edwards Air Force Base, the orbiter was ferried to Kennedy Space Center by 747 carrier aircraft for preparation for its next flight, STS 2. Delayed a month when oxydizer for the reaction control system spilled during loading and damaged thermal tiles, STS 2 was launched in November. The flight was shortened from five days to two after failure of one of the electrical power system's three fuel cells. Despite a shorter mission, STS 2—designed to test the orbiter systems further, including the remote manipulator system—was also successful. Returned to KSC on 25 November, *Columbia* at the end of the year was being prepared for its third flight, scheduled for March 1982.

Main Engine. The three high-pressure hydrogen-oxygen main engines in the Shuttle orbiter's aft fuselage each have a rated vacuum thrust of 2000 kilonewtons (470 000 pounds). A major advance in propulsion technology, the engines have a long operating life (7.5 hours, 55 starts) and the thrust can be throttled over a wide range (65 to 109 percent of rated power level).

The built-in electronic digital controller—the first to be used in a rocket engine—accepts commands from the orbiter for engine start, shutdown, and throttle change and monitors engine operation. It will automatically take action to correct a problem or shut down the engine safely if a failure should occur.

The engines performed flawlessly during both flights of *Columbia*, and postflight inspection revealed no significant discrepancies. A higher thrust version of the engine (109 percent of the present rated power level) was under development in 1981, and more than 14 000 seconds of engine test time had been accumu-

lated by the end of the year. After flight-certification testing, scheduled for completion by February 1983, this engine will be introduced into the orbiter fleet.

External Tank. The external tank, the structural backbone of the Space Shuttle during launch operations and ascent, contains 700 000 kilograms (2 million liters) of liquid hydrogen and liquid oxygen propellants for the orbiter's three main engines. The tank, 46.8 meters long and 8.4 meters in diameter, is composed of a large hydrogen tank and a smaller oxygen tank joined by an intertank structure. The external tank is protected thermally by superlight ablators in areas of high aerodynamic heating and spray-on foam insulation on other areas. The spray-on foam also prevents ice or frost formation, prevents air liquefaction, and reduces propellant boiloff. The only nonreusable portion of the Space Shuttle system, the tank is separated from the orbiter after main engine cutoff—before orbit insertion—and breaks up during descent over a remote ocean area.

The first and second flight tanks were successfully flown in 1981. The third was delivered to KSC in early October 1981. Three other tanks of the same design are in various stages of manufacture. Major welding and structural assembly have been completed on the first production version of a lightweight tank. At the end of the year, it was on schedule for delivery to KSC in September 1982.

Solid Rocket Booster. The solid-fueled rocket booster is the first designed to be reused. Standing 45.5 meters high, each with a solid-fueled rocket motor, two boosters provide a combined thrust of 23 575 kilonewtons (5.3 million pounds) at Shuttle liftoff. During 1981, the first two Shuttle development flights verified not only the capabilities of the Shuttle system to perform adequately during the missions, but also the reusability of the orbiter and the solid rocket boosters. Assembly of the boosters for flights STS 3 through STS 5 was in process during 1981, along with refurbishment of those used on the first two missions. Also under way were design of a lightweight booster case, design of a high-performance motor, and studies for performance enhancement.

STS 1 and 2 flights indicated some redesign was necessary for the booster aft skirts. Redesigns were in process, and repairs were begun to refurbish the STS 1 skirts. A series of production readiness reviews begun in 1981 will continue in 1982.

Launch and Landing. To serve both NASA and DoD needs for projected payloads, Space Shuttle flights will be launched from Kennedy Space Center in Florida and beginning in late 1985 from Vandenberg Air Force Base in California. Construction and activation of launch and landing facilities continued at both sites throughout 1981. The first line of processing facilities at KSC was completed and supported the first two Shuttle launches.

Flight Test Support. The mission control center and

Shuttle mission simulators supported the two Shuttle orbital flight tests in 1981 and at the end of the year were being configured to support a third R&D flight. Long-duration simulations were conducted and shorter simulations of ascent, orbit, entry, and approach and landing were being done. Payload operations were included in 1981; this activity will increase as the Shuttle reaches maturity. With the planned increase in the rate of Shuttle flights, mission simulators have been augmented for additional crew training and simulator software development. Using actual flight results, systems and procedures were being refined to streamline mission control, simulation, and training activities.

Follow-On Production. Building the remaining orbiters for a national fleet of four continued in 1981. The DDT&E (design, development, test, and evaluation) structural test article, being modified to become the second flight orbiter (orbiter 099) progressed substantially. Major structural elements were mated, final systems were being installed, and two-thirds of the required 30 800 thermal tiles were installed. This vehicle, named *Challenger*, is scheduled to be delivered in June 1982. Orbiter 103, *Discovery*, also progressed in 1981, with long-lead-time primary structures being fabricated and assembled. It is scheduled for delivery in September 1983. Long-lead procurement and parts fabrication continued for the fourth orbiter, *Atlantis*.

In the main engine program, production of full-power-level engines for development and certification testing and flight use continued. Engines 2008 and 2009 have been delivered. Engine 2010 was completed in September, but required modification of the main injector before the start of certification testing in December.

Construction of the second line of processing facilities at KSC continued on schedule for activation of the second Orbiter Processing Facility bay, mobile launch platform, and firing room in 1982 and other stations later. NASA also supported similar construction at Vandenberg. Procurement of crew equipment, flight spares for orbiter and main engine, and spares for ground support equipment continued as planned.

Upper Stages. Several upper stages were being developed for use with the Space Shuttle.

INERTIAL UPPER STAGE (IUS). The Department of Defense continued full-scale development of the IUS, designed to extend the reach of the Shuttle into higher earth orbits. The solid-propellant IUS and its payload will be deployed from the orbiter in low earth orbit, and the IUS will boost the payload to a higher energy orbit. NASA and DoD will use the IUS primarily to achieve geosynchronous orbit. NASA was coordinating non-DoD requirements into the DoD IUS program to ensure its utility for NASA and commercial applications. Hardware development was proceeding on a schedule for a 1982 launch on the Titan

launch vehicle and an early 1983 launch of the Tracking and Data Relay Satellite from the Space Shuttle.

CENTAUR/STS. NASA contractors were studying modifications of the Centaur upper stage for possible use with the Space Transportation System for planetary and heavier geosynchronous missions. The modifications would increase the size of the propellant tanks to add about 50 percent more propellant capacity and make the stage compatible with the Shuttle.

SPINNING SOLID UPPER STAGE (SSUS). Qualification continued for the two sizes of the SSUS being developed by members of the U.S. aerospace industry, at their own expense, for launching smaller spacecraft into geosynchronous-transfer orbit. SSUS-D is configured for satellites that have been using the Delta expendable launch vehicle, and SSUS-A for those using the Atlas-Centaur. Many components and subsystems had been qualified, and integrated system testing was under way. Production and assembly of flight hardware continued. NASA has ordered the SSUS-A for Intelsat V missions, and commercial users are buying the SSUS-D from the developer and through suppliers. The first two flights of the SSUS-D on Delta vehicles launched the Satellite Business Systems satellite *SBS 1* into orbit in November 1980 and *SBS 2* in September 1981. *RCA-Satcom 3-R* was also launched on a Delta/SSUS-D in November 1981. The first flight of the SSUS-D on the Shuttle will be in November 1982.

Advanced Programs

Systems to extend orbiter power and time in orbit, as well as free-flying platform systems to be deployed and serviced by the orbiter, were investigated in 1981. Studies included innovative equipment and tools to place, retrieve, and maintain or repair satellites in orbit; retrieve unstable satellites and space debris; and reduce cost of operations. Advanced development of improved crew systems and life support equipment continued.

Definition of the power extension package, which would provide the orbiter additional electric power by a solar array deployed from the remote manipulator, was completed. Concept studies of the solar electric propulsion system (SEPS) were completed. Two parallel definition studies were begun for the *Space Platform*, planned as a free-flying, Shuttle-tended, reusable spacecraft. The *Space Platform* will combine the 25-kilowatt power system and the Science and Applications Space Platform begun earlier.

Parallel concept-evolution studies for a space station began at the Marshall Space Flight Center and Johnson Space Center. The Marshall approach is a minimum space station evolving from the *Space Platform* and emphasizing science and applications uses. The Johnson study focuses on space operations in orbit. Concept studies of the reusable Orbit Transfer

Vehicle (OTV), to be based aboard the Shuttle or the space station, were continued in 1981.

Long-range planning toward future systems included extensive user analysis studies, space-station mission-model definition, and advanced operations techniques, particularly multiple-use geosynchronous platforms, large structures, and tethered satellites. A space station symposium of NASA organizations studying the space station was held at Michoud Assembly Facility in November 1981.

Studies began on advanced launch vehicle concepts emphasizing unmanned derivatives of the Space Shuttle. In one, a large unmanned payload carrier replaces the orbiter. In another, an unmanned launch vehicle uses clusters of the Shuttle solid-fueled motors with liquid-fueled upper stages.

Operation of the Space Transportation System

The Space Shuttle, scheduled to begin operational flights in November 1982, will begin an era of greatly increased R&D and commercial, industrial, and military uses of space. The Shuttle introduces a wide range of innovative launch and in-orbit services: multiple-payload launches; payload deployment, retrieval, and in-orbit servicing; manned laboratory research; routine, scheduled access to space; and opportunity for customers to charter a launch. The demand for the Space Transportation System now exceeds the capacity of the system. At the end of 1981, Shuttle flights were essentially sold out through 1986.

Policies and Procedures. Development and refinement of the policies governing use of the Space Transportation System continued throughout 1981. The policy for reimbursement of Spacelab services was undergoing a final revision before being published as a rule in the *Federal Register*. A policy to offer payload services in the orbiter mid-deck cabin area was being developed. In addition, issues were being identified to develop a policy for reimbursable operations at Western Space and Missile Center.

NASA had completed negotiations and signed launch service agreements with five users: INTELSAT, Satellite Business Systems, the governments of India and Indonesia, and the West German corporation Messerschmitt-Bölkow-Blohm GmbH. Additional negotiations were in process with 14 other users, all making payments or deposits toward STS flights. These payloads, NASA's own payloads, and firm commitments from DoD and other U.S. government agencies, will almost saturate STS operations through fiscal 1986.

The first launch service agreement for a small self-contained payload was signed in mid-1981, and the first small payload was scheduled to fly on STS 4. This payload, provided by five educational institutions, will include experiments on algae and duckweed growth in

space and also genetic studies of fruit flies and brine shrimp.

The price for Shuttle flights during the first three years of operations (1982-1985) was set in 1977 at \$18.3 million (1975 dollars, subject to escalation) plus a use fee of \$4.3 million (current dollars, not subject to escalation). The revised price applicable to flights in the fourth year of operations must be in place three years in advance. In keeping with this policy, NASA is in the process of establishing a new price for flights in 1986. At the same time, a full review of the policy is under way. Although the new price is expected to represent a significant increase over the existing price, the new price is expected to continue to be competitive with alternative methods of space transportation.

Spacelab

The Spacelab program, a joint endeavor by NASA and the European Space Agency (ESA), provides both a pressurized shirtsleeve laboratory (module) and unpressurized pallets to carry experiments and instruments into space in the cargo bay of the Shuttle orbiter. Spacelab can service a variety of experiments in one or many science disciplines and can be reused for as many as 50 flights. Under the 1973 agreement, ESA is responsible for the design, development, manufacture, and delivery to NASA of the first Spacelab flight unit, an engineering model, two sets of ground support equipment, and spares to support the first two Spacelab missions. The estimated ESA cost is about \$900 million. NASA is responsible for Spacelab operations and for peripheral equipment, such as the crew tunnel between the orbiter cabin and the Spacelab module. In addition, NASA agreed to procure at least one Spacelab production unit from ESA.

In 1981, ESA delivered the first Spacelab flight unit (long module and one pallet) and one set of electrical ground support equipment to Kennedy Space Center. This unit will be flown in the cargo bay of the orbiter in the latter part of 1983.

An engineering-model pallet, delivered by ESA in 1980, carried the OSTA 1 payload on the second Shuttle flight in November 1981. The Spacelab engineering-model module, also delivered in 1980, was reassembled at KSC and was being used to validate electrical ground support equipment and facilities. Production of the second Spacelab (follow-on procurement) was in process, with deliveries to KSC scheduled to start in the first part of 1982 and continue through 1984.

ERNO—European prime contractor for Spacelab development, in Bremen, West Germany—was integrating and testing the Spacelab hardware (pallets and an "igloo" to house subsystems) that will be flown on the Shuttle on the second Spacelab verification mission. Plans were to deliver this hardware to NASA by mid-1982.

Dornier Systems in Friedrichshafen, Germany, is building the Spacelab instrument pointing system (IPS) for ESA. The system, to be mounted on a Spacelab pallet, is being designed to point scientific instruments with an accuracy of 1 arcsec. A preliminary design review was completed in September 1981. The first instrument pointing system was expected to be delivered to KSC in December 1983 and to be flown on the second Spacelab mission.

The critical design review of the Spacelab Mission Simulator at Johnson Space Center was completed in May 1981. The simulator will be ready for training Spacelab crews by March 1983. The critical design review of the utility kits was also completed in 1981, and, in addition, all the ground Spacelab demultiplexers were delivered to NASA. Four sections of the crew tunnel were delivered to Kennedy Space Center.

Expendable Launch Vehicles

NASA launched missions on 11 expendable launch vehicles in 1981; 1 Scout; 5 Deltas, 2 with dual payloads; 4 Atlas-Centaurs; and 1 Atlas E/F (see launch table in appendix A-3). All but two were reimbursable launches for other agencies or commercial customers.

The smallest vehicle, Scout, launched a DoD navigation satellite, *Nova 1*. In five launches, Delta, NASA's most used launch vehicle, orbited seven satellites. Two of these launches put NASA scientific Explorer satellites into orbit: *Dynamics Explorer 1* and 2 on one Delta and the *Solar Mesosphere Explorer* (along with *UOSAT* for the University of Surrey, England) on the other—both launched from the Western Space and Missile Center in California. The other three Delta launches were for paying customers, including the *Goes 5* weather satellite for NOAA and two communications satellites, one for Satellite Business Systems and one for RCA. These were launched from the Eastern Space and Missile Center in Florida.

Atlas-Centaur, the largest expendable launch vehicle being used by NASA, launched four missions this year: *Comstar D-4*, a domestic communications satellite for Comsat Corporation; two Intelsat V communications satellites for INTELSAT; and the last in the current series of FLTSATCOM communications satellites for DoD.

Atlas E/F, a DoD-managed vehicle, launched the *Noaa 7* weather satellite for NOAA.

In addition, expendable launch vehicles continued to provide backup support to customers listed on Shuttle manifests during this early development and transition phase of the STS system. This backup capability will continue through at least 1985 to ensure a U.S. civil launch capability.

Space Research and Technology

The NASA space research and technology program develops a technology base for new or improved space capabilities. The program encompasses fundamental, discipline-oriented work and systems-oriented, focused technology programs.

Fundamental Research and Technology

Fundamental research and technology includes the key disciplines of chemical propulsion, electronics and automation, materials and structures, space power and electric propulsion, and aerothermodynamics.

Chemical Propulsion. Technology to extend the operational life of reusable rocket engines continued to show progress with the demonstration of longer-life "hybrid" bearings for cryogenic propellant service. In tests, these combination ball-bearing and hydrostatic-bearing designs demonstrated lifetimes several times that of conventional ball bearings.

Electronics and Automation. A special-purpose "pipe-line" processor designed for robotic vision applications was demonstrated for the first time in the laboratory. The device will make possible visual tracking of objects at a rate of 30 video frames per second, adequate to provide robotic-system-control response comparable to human performance in many applications. Vision is the most valuable sensory feedback to the control of robotic devices, necessary for automated satellite servicing as well as space assembly and construction. The demonstration was a major step toward a control-oriented computer vision system for space robotics.

An experimental computer program for automatically planning and scheduling spacecraft action sequences was developed. The program combines, for the first time, artificial-intelligence technology with operations research and discrete-event simulation techniques to perform automatically tasks that usually require a cadre of mission operations personnel.

A technology with potential impact almost equivalent to the integrated circuit is fiber optics and optical signal processing. During 1981, a light-emitting-diode (LED) laser was switched on and off with a light pulse width of several tens of picoseconds (trillionths of a second). Technological ramifications are sweeping and will permit gigabit data rates on fiber-optic data lines, laser ranging to within millimeters, and an application called "optical time-domain reflectometry," in which single defects in fiber optic systems can be detected within millimeters rather than meters.

Materials and Structures. Development of advanced ceramic tile progressed for the thermal protection system of the Space Shuttle orbiter. New material—fibrous, refractory, composite insulation (FRCI)—offers lower-cost, more durable protection. Addition of aluminum borosilicate fibers to the silica fiber now in

use formed a new material with unique physical, mechanical, and thermal properties. It has higher strength and greater resistance to impact damage and is expected to save some 500 kilograms in the weight of each orbiter, while increasing the designed safety margin.

Space Power and Electric Propulsion. Progress also was made in the space nuclear-reactor power system, which will make possible exploration of the outer planets and other missions requiring high power independent of sunlight. During 1981, NASA and the Department of Energy established a jointly funded and managed program in the critical barrier technologies for space reactor power systems. The most difficult outer planetary missions can be accomplished using a 120-kilowatt uranium-oxide-fueled reactor and silicon-germanium thermoelectric converters. System design for the entire nuclear-reactor power subsystem is in progress. Emphasis is on evaluating important alternatives such as the heat-source converter interface (conduction vs. radiation) and the working fluid of heat pipes. The component technologies may be ready for system demonstration on the ground in the middle to late 1980s.

The first automated space power subsystem was successfully demonstrated during 1981. This work provided the first concrete measures of cost and benefits that can be expected of future automation. To support high-power uses of space platforms, NASA investigated interactions between high-voltage spacecraft systems and the ambient space plasma. Substantial progress was made toward developing an analytic computer model as a design tool for future power platforms in geosynchronous orbit or low earth orbit.

Aerothermodynamics. An important molecular transition was experimentally confirmed for the carbon C_3 molecule. A portion of this molecule's ultraviolet-absorption spectrum previously reported in the scientific literature was erroneously attributed to another hydrocarbon molecule. The absorption properties of carbon species are critical in determining the extent to which gases given off by carbon heatshields are successful in protecting a planetary entry probe released from the proposed *Galileo* spacecraft entering the Jovian atmosphere. The new ultraviolet molecular-absorption spectrum for C_3 reduces the predicted heating about seven percent—a significant reduction for this probe.

A new computational technique was developed for analyzing the hypersonic, three-dimensional flow field around "shuttlelike" space transportation vehicles. Until the present development, no solutions were possible for these configurations at large angles of attack. The new technique will greatly assist analysis of flight data obtained from the Shuttle orbiter during reentry. It also can be used as a design tool for advanced space transportation systems.

The systems research and technology program exploits the basic understanding of physical principles derived from discipline-oriented effort and focuses work on advanced subsystem and system applications. Principal areas of activity include transportation, spacecraft, and information systems. Significant progress was made in all areas.

Transportation Systems. The aerodynamic-coefficient identification package (ACIP) provided unique research data on the entry aerodynamics of the first and second Space Shuttle flights. The precise measurements substantially aided verification of entry performance and will provide designers of future vehicles with validated design and performance criteria.

Spacecraft Systems. Two technology experiments, the feature identification and location experiment (FILE) and the induced environmental-contamination monitor (IECM), were flown on the November Shuttle flight. IECM gave NASA its first look at the Shuttle particulate and molecular environment and provided initial data for assessing the effect of the environment in the Shuttle bay on future payloads. FILE classified ground features such as water, bare land, and vegetation in real-time. In the future, the FILE system will be expanded to include identification and tracking of clouds, snow, and ice.

Information Systems. The traveling-wave tube is used as a microwave power amplifier because of its ability to achieve high-power gain over a wide band, but application of this technology to space systems has been limited by high secondary electron emissions generated by tube electrode materials. In 1981, new collector material was developed that decreases the secondary electron emission to one-fourth. This unique material is ion-beam-textured pyrolytic graphite, whose surface is characterized by densely packed micron-sized spires. Initial tests of the first traveling-wave tube with a pyrolytic graphite collector substantiated a significant increase in efficiency and lifetime of space tubes.

An interim, digital, synthetic-aperture-radar (SAR) processor was developed in 1979 by JPL to process limited amounts of *Seasat* SAR data. An upgraded system developed in 1981 employs three floating-point, system-array processors working simultaneously on different parts of the process—to reduce processing time for a 100- by 100-kilometer SAR image from 10 hours to 2.6 hours.

The ability to make planetary observations over different spectral regions with sufficient sensitivity to obtain useful data from low-emission sources will greatly enhance knowledge of our planetary system. During 1981, a 20-element infrared-imaging array tested on the 155-centimeter Mount Lemmon, Arizona,

telescope demonstrated the first astronomical application of this technology by imaging two stars.

Lasers show great promise as spaceborne ranging instruments to determine orbits precisely, study the earth's gravitational field, measure tectonic plate motion, and determine crustal deformation. Use of lasers, however, has been limited by the capability of available components. During 1981, two essential components, under development for several years, reached the demonstration stage. A compact, yttrium-aluminum-garnet laser transmitter achieved single-pulse energy of six millijoules with a pulse length of 200 picoseconds (200 trillionths of a second). The other component, a new ranging receiver, has single-photoelectron sensitivity and 17-picosecond resolution. Over a one-kilometer path, this new transmitter-receiver combination reduced range uncertainty to four to six millimeters.

NASA Energy Programs

NASA supports the Department of Energy and other agencies, on a reimbursable basis, by developing energy technology. In 1981, progress was made in automotive research and development, overseas application of wind energy, terrestrial solar-cell development, and overseas application of solar energy.

Automotive Research and Development. NASA's support of DOE's vehicle and engine R&D programs includes development of gas turbines, the Stirling engine, and electric and hybrid vehicle-propulsion systems. In the Stirling engine project, the team of Mechanical Technology, Inc., and United Stirling of Sweden demonstrated an intermediate-temperature experimental engine with efficiency equal to that of automotive diesel engines and with emissions less than EPA research goals.

Research continued in the development of advanced AC and DC electric vehicle-propulsion systems and components. The first experimental AC propulsion system was extensively tested in 1981, yielding an overall predicted efficiency of 82 percent, equal to the demonstrated efficiency of a previously tested DC system. Both systems appear to have great potential for improving performance and lowering the initial cost of electric vehicles. Progress has also been made in reducing the weight of DC traction motors. Tests by Garret and Virginia Polytechnic Institute of electronically commutated experimental motors—one-fifth to one-half the weight of conventional motors—indicated an efficiency comparable to that of a conventional motor and controller.

Wind Energy. The nation's first "wind farm," consisting of three of the largest advanced wind turbines developed by NASA and DOE, began operation at Goodnoe Hills, Washington, during 1981. Each wind turbine has a two-bladed rotor, 92 meters from blade tip to blade tip, and can produce 2500 kilowatts of

power. If the turbines are produced in quantities of 100 a year or more, units following the first 100 could produce energy at an estimated five cents per kilowatt-hour. This price is competitive with conventional oil-fired electric power in many areas of the country. In initial operation of all three machines, interaction of the large units operating close to each other—150 to 900 meters apart—caused no problems. Electrical output has been at the predicted level.

The four intermediate-size (200 kW) wind turbines—at Clayton, New Mexico; Culebra, Puerto Rico; Block Island, Rhode Island; and Oahu, Hawaii—had operated for more than 30 000 hours and generated more than 3 million kilowatt-hours of power by the end of 1981. Experience with these increasingly reliable machines, each operated by a local utility, aids evaluation of new components and improved systems and investigations of utility interface problems. Original 38-meter (tip to tip) aluminum rotor blades were replaced with blades of laminated wood or fiberglass. So far, operation of the new blades has been excellent.

Terrestrial Solar-Cell Development. Technology for producing low-cost, single-crystal silicon material was advanced by improved methods for purifying silicon and for producing thin silicon sheet by ribbon-crystal-growth processes. Encapsulation system designs were developed to meet stringent durability and low-cost requirements. Advanced automation technology was used to assemble solar cells into encapsulated modules.

Overseas Applications of Solar Energy. NASA supported DOE in planning the installation of standardized solar-cell systems for health service, water, education, and public lighting in four villages in Gabon, Africa. Development of solar-cell-powered refrigerators and freezers continued, jointly funded by DOE and the Center for Disease Control, for cold storage of vaccines in remote medical posts. The first was installed at the Bhoorbora Health Clinic in India. Others are scheduled for the Maldiv Islands, Gambia, Ivory Coast, Colombia, and Peru.

NASA also continued technical support to the Agency for International Development (AID). The solar-cell system for pumping water and grinding grain in Upper Volta was doubled in power to 3.6 kilowatts with modules supplied by DOE. Responding to a need of the international health assistance community, standard solar-cell packages are being developed to provide basic electrical service to rural health clinics in Ecuador, Guyana, Zimbabwe, and Kenya. A project was begun with Tunisia to demonstrate the ability of solar energy to supply the minimum services necessary in the village of Hamman Biadha and in rural agricultural settings. Planning assistance was also provided for a possible project in Egypt for solar-cell power generation, wind power generation, solar heating and cooling, and solar process heat.

Space Tracking and Data Services

NASA tracking, command, telemetry, and data acquisition supports earth-orbital science and application missions, planetary missions, sounding rockets, research aircraft, and all phases of the Space Shuttle flight program. Two worldwide tracking networks, one for deep space missions and one for earth-orbital, provide this support. A global communications system links tracking sites, control centers, and data processing facilities, for both real-time and more routine data processing.

Network Operations

During 1981, the tracking work load remained high, supporting some 45 missions, including the first two Space Shuttle flights and the launch and orbit phase of low earth-orbital missions such as the Solar Mesosphere Explorer *SME* and Dynamic Explorers *DE 1* and *2*. Both launch and in-orbit support were also provided for missions of foreign countries, other government agencies, and commercial firms. For Space Shuttle missions, three new sites for UHF air-to-ground voice operated in Senegal, Botswana, and Australia, as well as three Shuttle-unique stations in Florida, California, and New Mexico. DoD tracking and telemetry elements also supported Shuttle flights.

The outstanding accomplishment of the Deep Space Network (DSN) during 1981 was its support of *Voyager 2*'s encounter with Saturn and its rings and satellites during August. At each of the deep space stations—Goldstone, California; Madrid; and Canberra, Australia—the DSN's 64- and 34-meter antennas communicated with *Voyager 2*, performing almost flawlessly. Some 99 percent of the imaging data transmitted by the spacecraft was received. The return from the radio science system was equally successful, with no known data gaps. During 1981, the DSN also supported *Voyager 1*, *Pioneer 6* through *12*, *Helios 1*, and the Viking lander on Mars.

The 26-meter antenna at each of the three stations was closed down on 1 December, for a substantial saving. The 34- and 64-meter antennas will continue to support deep space missions.

Data Systems and Control Centers

Six NASA control centers supported requirements for 20 to 25 spacecraft during 1981. One of the six was closed with the termination of Orbiting Astronomical Observatory (OAO) support. A new center was being prepared for the upcoming *Space Telescope* mission. Control centers (1) issue commands to operate the spacecraft and their sensors and (2) monitor power status and thermal conditions. Computers calculate the spacecraft orbit, compute the attitude of the craft

to assist in maneuvers, and manage command memory.

Tracking and Data Relay Satellite System (TDRSS)

The TDRSS, a leased service system of two data-relay satellites, is to take over tracking and data acquisition for low earth-orbiting spacecraft in 1984. TDRSS will permit station closings, network consolidation, and automation of some operations, enhancing capability and economic operation. NASA has entered a 10-year contract for this service. NASA continued development of software for the Network Control Center. Launch of the first satellite, TDRS-A, was planned for a Space Shuttle flight in January 1983.

Work was under way to consolidate the three remaining Spaceflight Tracking and Data Network stations—also in Goldstone, Madrid, and Australia—with the Deep Space Network facilities under Jet Propulsion Laboratory management by the mid-1980s. The combined network will continue support for high elliptical, synchronous, and deep space missions at significant cost savings, after TDRSS takes over the low earth-orbit missions.

Aeronautical Research and Technology

NASA's aeronautical research improves the performance, efficiency, and safety of existing aircraft and develops a base of advanced technology for the next generation of civil and military aircraft. Objectives include maintaining a strong technological base, improving aircraft safety, and providing technical support for the military.

Maintaining a Strong Technology Base

NASA's aeronautical research and technology program includes disciplines broadly categorized as aerodynamics, materials and structures, propulsion, and electronics and human factors.

Aerodynamics. Important advances were made in using high-speed computers to predict aerodynamic behavior. An algorithm was discovered that permits a tenfold increase in computational speed when calculating forces and flow velocities over airfoils, wings, and bodies. The new procedure has been independently checked and is being adopted by researchers all over the world.

Until recently the friction drag associated with turbulent flow on surfaces of aircraft and missiles has been considered to be fixed by natural laws and hence not subject to reduction. However, new data have shown the possibility of reducing friction 20 percent or more by attaching devices that break up large eddies. Test data are being verified in several different test facilities, after which the devices will be tested in

flight. Reducing friction drag 20 percent would be economically important, and the devices may be appropriate for retrofitting aircraft already in service.

Materials and Structures. Development of advanced computer software and hardware continued to be important in structural analysis. Development of general computer-aided design (CAD) systems, critical to improving productivity, continued. A newly developed prototype for managing a data base, called relational information management (RIM), was released to NASA centers and industry for evaluation. It can efficiently tie together many different analysis, design, and manufacturing programs into a cohesive general system using a common data base. Preliminary results with RIM indicate that it has high potential for designing and evaluating new aircraft concepts much more quickly and cheaply than previously available methods using models, wind tunnels, etc.

In composite primary structures for airframes and engines, a new class of resins was developed in 1981. The resins hold promise for greater damage tolerance and greater processibility, which should expand the use of composites. The new materials, thermoplastic polyimides, can be used as a composite matrix resin and for fibers, films, and adhesives. Their high-temperature capability should lead to use in aircraft engine structures, saving considerable weight over present materials.

Propulsion. During 1981, a major step toward improved fuel efficiency in commercial high-bypass-ratio turbofan engines was achieved in the energy-efficient engine program. Performance goals were demonstrated in component rig tests of the fan, high-pressure compressor, combustor, low-pressure turbine, and the exhaust gas mixer. Of special note, the high-pressure compressor achieved a pressure ratio of 23:1 in only 10 stages of compression while maintaining excellent efficiency levels. The technology developed will provide fuel savings in advanced turbofan engines of up to 20 percent over today's most efficient engines.

Transmission research focused on evolutionary improvement in gears, bearings, lubricants, and traction drive systems, as well as verification of new transmission concepts that provide long-life, reliable, lightweight, and quiet transfer of mechanical power for rotorcraft and turboprops. During 1981, efficiency testing demonstrated that proper selection of lubricant chemistry can reduce transmission power losses by as much as 25 percent. NASA-developed analytical codes for bearings also optimized the design of high-speed, tapered roller bearings that increased speed capability 30 percent over that permitted by existing bearings.

Electronics and Human Factors. During 1981, NASA and the Federal Aviation Administration jointly developed human factor guidelines for advanced information-display concepts that promise to permit aircraft to fly closer together with no decrease in safety. Head-up display (HUD) and cockpit-display-of-

traffic-information (CDTI) concepts were evaluated. HUD research assessed two major alternatives, delineated the errors, and prescribed methods of minimizing those errors. CDTI simulation studies evaluated the ability of pilots to use a cockpit display of nearby traffic to perform merging, spacing, and other maneuvers in instrument flight conditions that now can be performed only with airspeed and vector commands from Air Traffic Control.

Modern flight-control-system designs employing digital computers incorporate an independent backup computer. Recent research has focused on a technique of embedding backup software within the primary control system computers, thus eliminating the need for additional hardware. Laboratory tests demonstrated the effectiveness of this technique in reducing cost and complexity of future digital flight-control systems.

Reducing Energy Consumption

In 1981, NASA continued to develop technology toward the goal of 50-percent improvement of energy efficiency in derivative and future subsonic, commercial transport aircraft.

Engine Systems. Investigation of fuel-saving improvements in existing or derivative JT8D, JT9D, and CF-6 turbofan engines were completed. Of the 16 engine components or system modifications tested for performance improvement, 13 are likely to be put into service with subsequent recoupment of government investment. Fuel savings for the individual improvements range from 0.1 to 1.8 percent. Engine diagnostic investigations identified sources of performance deterioration and showed the effects of aerodynamic nacelle loads on engine clearances and seal wear. Major benefits will accrue in new engine designs.

Advanced high-speed turboprop technology was further explored during 1981 through extensive experiments and analyses. Wind-tunnel tests of subscale propeller models established flutter-free design conditions and confirmed the attainability of high efficiency. Predicted noise levels were confirmed in flight, and measurements of wing-installation drag revealed ways of tailoring local wing and nacelle contours to eliminate interference. Predicted noise reduction from fuselage wall concepts was validated by large-scale ground tests.

Aerodynamics Systems. NASA aeronautics research and management of contracts with the civil transport industry focused on energy efficient concepts for one of the nation's top export items, commercial transports.

Reduced-static stability components, expected to save 4 percent in fuel, were bench-tested and flight-tested on an L-1011 transport in 1981. And aerodynamic research on high-aspect-ratio, sailplane-

like supercritical wings at NASA and Douglas Aircraft Company showed that such wings on new transports can save 10 to 15 percent in fuel. Flight-research evaluation of the aerodynamics and inertia loading on the B-747 nacelles was completed. The data will be used to develop theoretical design codes to tailor the nacelle and pylon shapes and to optimize the design technique for engine mounting.

Structural Systems. Three programs researching graphite-fiber-reinforced composites for secondary structures on transport aircraft were completed in 1981. These components, with medium-primary structural components being developed in three other programs, are expected to save 25 percent in weight, leading to 3-percent fuel savings in transports.

FAA certified the Lockheed L-1011 composite aileron, which will soon join the Douglas DC-10 rudder and the Boeing B-727 elevator in flight service. Design, fabrication, and structural testing of the Boeing B-737 horizontal stabilizer, a medium-primary composite component, progressed well. The tests and analyses required by FAA for certification, which is expected in early 1982, were completed. Airlines have already accepted two sets for delivery on operational aircraft next spring.

Improving Aircraft Safety

Progress was made in 1981 in defining atmospheric hazards and advancing fire-safety technology. To protect advanced electronic and composite structures, aircraft designers need a definition of lightning hazards. The 1980 data base of direct lightning strikes on the F-106 research aircraft was doubled during 1981.

In cooperation with FAA, NASA continued development of advanced, fireworthy, lightweight materials to reduce the threat of fire in aircraft cabins. Substantial progress was made in increasing fire resistance and decreasing toxicity of seat cushions and panels, the major combustible and toxic materials. In addition, comprehensive studies of worldwide transport accidents identified structures requiring research to improve occupant survivability in crashes.

Advancing Long-Haul and Short-Haul Aircraft

NASA continued to develop technology for efficient, economical, safe, reliable, and environmentally compatible long-haul and short-haul aircraft. Considerable progress was made in research for general-aviation aircraft.

Full-scale, experimental, aircraft crash data validated improved methods for dynamic testing of seats. The methods will assist the FAA in developing certification procedures. A major computer program for dynamic analysis of nonlinear structures under crash conditions was also verified.

Research to reduce general-aviation-aircraft drag emphasized developing and maintaining natural laminar flow on wings. Laminar-flow airfoils were investigated during full-scale flight tests completed in 1981. Evaluation, on four aircraft, of transition sensitivity to real-world effects such as airfoil manufacturing imperfections, insect residue on surfaces, and rain confirmed wind-tunnel data and theoretical predictions.

Research on intermittent-combustion engines emphasized improved fuel economy and multifuel capability. Modifications in a standard general-aviation, air-cooled, gasoline-fueled, reciprocating engine decreased fuel consumption 10 to 30 percent during ground and flight tests. Research emphasis is shifting to unconventional internal-combustion engines that can burn jet engine fuel, to relieve dependency on scarce and expensive aviation gasoline. Engine configurations include rotary combustion and diesel designs. Efforts to reduce propeller noise led to the development of noise-prediction techniques, which were confirmed by tests.

Research in avionics, controls, sensors, and human factors for general aviation focused on improving single-pilot operations under instrument flight rules. Flight of the experimental, demonstration advanced-avionics system substantiated for the first time the basic concept of integrated and pilot-interactive electronic displays for many navigation and flight management functions. Flight-simulator research showed the potential of a simple, automated terminal-approach system for single-pilot operation, as well as an electronic display for visual reference and guidance both en route and in the terminal area.

Technical Support for the Military

Broad-based technology for future military aircraft is one goal of NASA's aeronautical research.

Highly Maneuverable Aircraft Technology (HiMAT). The HiMAT remotely piloted research vehicle investigates advanced high-risk technology for high-performance fighter aircraft. During 1981, flights concentrated on reaching high transonic and supersonic speeds. The flight envelope was expanded

to mach 0.95, and the vehicle achieved a more than 7-g load factor in the stable configuration.

Tilt-Rotor Research Aircraft. The full flight envelope of the NASA XV-15 was demonstrated in 1981, completing the proof-of-concept phase. The second phase, concept evaluation, was begun with one aircraft flying to gather detailed engineering flight data to document performance, flight dynamics, and stability and control characteristics. The second aircraft began mission task demonstrations for the Navy and Army. It was also exhibited—to great interest—at the 1981 Paris Air Show.

Rotorcraft. Full-scale rotor activity centered on completing documentation of characteristics of the bearingless main rotor (BMR), the XH-59 advancing-blade-concept aircraft, and the X-wing high-speed demonstrator. A rotor for higher harmonic control (HHC), which has potential for dramatically reducing vibration, was flight-tested in October 1981 on an Army OH-6. The predicted vibration levels were confirmed.

Small-scale testing in NASA tunnels helped determine the optimal tip shapes for reducing loads, noise, and interference aerodynamics on advanced rotor blades for the UH-1. Associated analysis in acoustics, aeroelasticity, and performance was confirmed by wind-tunnel results, which suggested further tests of more optimized configurations.

V/STOL Aircraft Technology. The first phase of the cooperative program with the Navy and industry to develop aerodynamic technology for V/STOL fighter-attack aircraft was completed. Four contractors studied six twin-cruise-engine concepts, which were tested in NASA wind tunnels over a speed range of mach 0.2 to 2.5 with angles of attack up to 90°. A similar joint program was begun to define the most promising concepts for a single-cruise-engine V/STOL fighter.

The program to demonstrate a vented-thrust deflected nozzle coupled with a high bypass-ratio turbofan engine was completed. Good performance was achieved with no adverse ground effects. Neither high-temperature materials nor cooling air will be required for this nozzle; hence cost and weight will be reduced.

Department of Defense

To maintain the security of the United States, the Department of Defense (DoD) pursues advances in space communications, navigation, meteorology, surveillance, and aeronautics. Cooperation with NASA and other federal agencies also produces civil benefits.

In 1981, DoD continued to expand and upgrade satellite communications, including a design for a new worldwide system, MILSTAR. The first Nova satellite was launched in May to add a longer-life spacecraft to the Navy's worldwide Navigation Satellite System, TRANSIT; and full-scale development of the Global Positioning System continued. Research in infrared technology made progress for missile surveillance and warning. DoD preparations anticipated broadened capabilities with more nearly routine operations in space as the reusable Space Shuttle completed its first two orbital test flights. The DoD-developed inertial upper stage that will boost payloads from the Shuttle into higher orbits was scheduled for first launches on the Titan launch vehicle in 1982 and the Shuttle in 1983. The department also made progress in developing new aircraft structures, concepts, and designs, including the multirole B-1B bomber.

Space Activities

Military Satellite Communications

The Department of Defense has identified three categories of military satellite communications requirements: (1) high-capacity worldwide communications for fixed and transportable users, (2) medium-capacity worldwide communications for mobile users, and (3) low-capacity communications for command and control of nuclear-capable strategic and tactical mobile forces. Military satellite communications systems must be hardened against nuclear effects, made resistant to jamming, encrypted, and protected against antisatellite weaponry. The Defense Satellite Communications System (DSCS), designed to serve high-data-rate users, consists of four active satellites and two on-orbit spares. Mobile users are supported by the Fleet Satellite Communications System (FLTSATCOM), consisting of four FLTSATCOM satellites and leased tactical service provided by commercial Maritime Satellite System (Marisat) satellites.

This system may be enhanced with the launch of additional FLTSATCOM satellites and commercially leased LEASAT satellites. Nuclear-capable forces are supported by the Air Force Satellite Communications System (AFSATCOM), which consists of transponders on FLTSATCOM, the Satellite Data System (SDS) spacecraft, and other host satellites.

MILSTAR. DoD developed a conceptual design in 1981 for a new military satellite communications system, MILSTAR, to operate at extremely high frequency (EHF) for jam-resistant communications. Satellite cross links will permit worldwide interconnection of all military forces. The system will be used by the U.S. Army, Navy, and Air Force. A common-terminal development program will ensure interoperability.

Fleet Satellite Communications System (FLTSATCOM). Providing moderate-capacity, mobile-user service in a worldwide communications system, FLTSATCOM satisfies the most urgent tactical-peace-time and crisis-management communications requirements of the Navy and commanders-in-chief of the unified and specified commands, as well as communications requirements of the strategic forces. The fifth FLTSATCOM satellite was launched August 1981, but structural damage during orbit insertion permitted only limited communication operations. Installation of fleet broadcast receivers was virtually completed. Equipment for reliable, long-range, secure voice operation was installed in 431 ships by the end of 1981. Shipboard terminal equipment will operate with both Marisat and FLTSATCOM systems.

Navy Satellite Communications Activities. The LEASAT arrangement was revised to make it compatible with Space Shuttle availability. The first LEASAT launch was expected in 1984. The EHF communications ship terminal to operate with MILSTAR was defined and ready for full-scale development. During 1981, the DSCS II terminal aboard U.S.S. *Kitty Hawk* completed operational evaluation, and United Kingdom submarines began receiving FLTSATCOM/SSIXS submarine communication terminals.

Army Satellite Communications Activities. The Army develops, procures, and supports ground terminals for strategic and tactical satellite communications. Two major projects are the Defense Satellite Com-

munications System (DSCS) Phase II and the Ground Mobile Forces Tactical Satellite Communications (GMF-TACSATCOM). Another conducts exploratory development to support the two major Army projects and other space programs being developed by DoD.

Nineteen additional, medium, satellite terminals were approved for procurement for the DSCS. These AN/GSC-39 terminals will be upgraded to include the latest technology and, with the 21 previously approved, will replace the obsolete AN/TSC-54 and AN/MS-46 terminals. The real-time adaptive-control subsystem begun in 1980 will, when completed in 1985, provide the DSCS a computerized and fully automated system to control the DSCS III satellites and their communications. The 35 digital subsystems shipped to the field were being phased into operation at the end of 1981. Delivery of the new spread-spectrum, multiple-access AN/USC-28 units began in November 1981; all 51 were scheduled to be incorporated into the system by mid-1983. A contract for 32 jam-resistant, secure-communication terminals (AN/GSC-49) for the Worldwide Military Command and Control Systems Program was awarded, with deliveries to begin in January 1983.

Tactical Satellite Communications (TACSATCOM). First deliveries of 227 additional multichannel, superhigh-frequency (SHF) tactical terminals—following on the first purchase of 31 terminals—were scheduled for 1982. Contract negotiations were completed for production of 174 UHF man-pack terminals, with delivery to begin in 1983. Development of an EHF, single-channel terminal (SCOTT) for ground-mobile forces was under way, for operation with MILSTAR. The terminals should reach the field in the late 1980s.

Advanced Space Communications Technology. A program developing and demonstrating advanced technologies for spacecraft and for airborne and ground terminals meets evolving DoD needs for military satellite communications. In 1981, advanced development models of the command-post modem-processor and small SHF-EHF airborne terminal were delivered for testing. Tests are to demonstrate feasibility of an airborne satellite terminal to provide secure voice and teletype communications between airborne command posts and bombers and missiles under severe jamming. A system will be developed to operate with MILSTAR.

Submarine Laser Communications. The joint Defense Advanced Research Projects Agency and Navy Submarine Laser Communications (SLC) Program is developing the technology to communicate from space, using a blue-green laser beam, through clouds and water to submarines at operational depths without compromising their security or limiting their flexibility. While early tactical SLC capabilities are expected from an airborne system to cover limited areas, a space SLC system is highly desirable for global

coverage, survivability, and flexibility in both tactical and strategic operations. In early 1981, technology advances in optical receivers permitted experimental verification of SLC communications from aircraft through clouds and water to a submerged submarine. While not an operational demonstration, the test validated performance predictions.

Navigation

The Navy Navigation Satellite System (TRANSIT) completed 16 years of operation in 1981. TRANSIT provides worldwide positional data for strategic-ballistic-missile submarines and many other military and commercial users. The first Nova satellite, designed for longer life than previous TRANSIT satellites, was launched in May 1981.

The developmental NAVSTAR Global Positioning System (GPS) continued in 1981 to provide up to six hours a day of accurate positioning worldwide with five of its six satellites in space (one was not operating and a December launch was aborted when the Atlas launch vehicle failed). A joint program of the Air Force, Army, Navy, and Defense Mapping Agency, GPS also has representatives from the Department of Transportation and nine North Atlantic Treaty Organization (NATO) countries. It will improve weapon delivery and worldwide, rapid force deployment with continuous, precise, three-dimensional positioning and navigation. By late 1988 the operational 18-satellite constellation will be able to provide positioning information accurate to 16 meters, velocity accurate to 0.1 meter per second, and time synchronized to within 0.1 microsecond. DoD users benefit from the common positioning grid, superior accuracy, and global coverage of NAVSTAR. The reliability of a system unaffected by weather and concealed by passive operation (users do not radiate any energy) also improves weapon delivery, intelligence, and reconnaissance capabilities.

Full-scale development of GPS began in July 1979. Because of the wide range of requirements, unique-user equipment was being developed to satisfy the needs of the Army, Navy, and Air Force. F-4 bombing and helicopter rendezvous were demonstrated with excellent results. In addition, a low-cost prototype receiver navigated a United Kingdom aircraft over the North Pole. Terrain-following tests with a helicopter equipped with a GPS set were successful, and a receiver was used on a French maritime patrol aircraft. The Landsat-D satellite, to be launched in 1982, will use GPS to determine satellite positions in space for correlation with earth photography. The Defense Mapping Agency is developing geodetic user equipment to exploit GPS in support of many mapping, charting and geodesy missions.

The Defense Meteorological Satellite Program (DMSP)—supporting DoD's strategic and tactical needs for weather information—requires at least two satellites operating continuously in orbit to obtain information from all points on the earth at least four times each day. Global weather data are stored on the satellites and later transmitted to the Air Force Global Weather Center or to the Navy Fleet Numerical Oceanography Center. Regional weather data, transmitted in real-time to transportable read-out stations at key locations worldwide, also support Army, Navy, and Air Force tactical operations.

Surveillance and Warning

Early Warning Satellites. Satellites provide early warning data to the National Command Authorities, the Strategic Air Command, and the North American Air Defense Command. In 1981, design improvements to increase survivability were begun, modifying ground terminal equipment as well as the spacecraft.

Space and Missile Surveillance Research. Research programs continued to develop sensors and collect data on backgrounds for application of infrared technology to surveillance and warning missions. In missile surveillance technology, new infrared-measurement hardware was purchased during 1981 to improve the accuracy and effectiveness of rocket and balloon flights planned for 1982. Infrared data on earth backgrounds and rocket engine plumes will make a major contribution to system design for a space-based missile-surveillance system. In space surveillance technology, the space infrared sensor was completed and awaits a decision to launch. Four sounding rocket probes measured infrared background in 1981.

The Navy, Air Force, and DARPA in 1981 accelerated development of advanced concepts and technology for strategic and tactical surveillance from space. Programs to demonstrate these technologies in system-level proof-of-concept experiments continued. A joint technology-development program for improved strategic infrared surveillance has been planned and budgeted.

Development of infrared-mosaic-detector arrays, onboard signal processing, cryogenic refrigerators, large optics, and structure technology for surveillance continued. Preparation of the Teal Ruby experiment to qualify first-generation infrared-mosaic detectors in space continued toward Space Shuttle launch in 1983. Development of components and concepts continued for space-based radar, including transceiver modules; large, lightweight, phased-array antennas; and onboard signal-processing components. DARPA continued analysis for the Talon Gold experiment to develop space technologies for precision acquisition, tracking, and pointing at long range. The Navy in-

itiated the integrated tactical-surveillance system (ITSS) program to optimize the role of aerospace platforms and sensors working with other surveillance and command, control, and communications systems in support of offensive and defensive fleet operations.

Ballistic Missile Early Warning System (BMEWS). Studies begun in 1980 to identify ways to upgrade or replace the Distant Early Warning (DEW) Line and BMEWS—which make up the U.S. atmospheric tactical warning system, constructed in the 1950s—continued in 1981. Both space- and ground-based alternatives were under consideration, including near-term and far-term multimission space-based proposals.

Detection from Space—Advanced Microwave Technology. Development continued on miniature, low-cost, radar transceiver modules using integrated circuits. Low cost-to-weight ratio and high efficiency of the modules are key factors in determining use in space-borne radars, as well as other phased-array radar and communication applications in airborne and surface systems. A silicon-on-sapphire MOSFET power amplifier has been demonstrated. Improved designs for low-noise amplifiers, phase shifters, and passive transmit-and-receive switches were soon to be evaluated. Fabrication and testing of fully integrated modules were planned for late 1982. Similar critical components in gallium arsenide technology have been demonstrated, and improved designs will be evaluated in 1982. Work continued to demonstrate antenna pattern performance of candidate space-borne, phased-array-radar membrane structures.

Space Transportation

Expendable Launch Vehicles. The U.S. space program's total of 16 successes in 17 launches on expendable launch vehicles in 1981 included 5 by DoD and 2 DoD satellites launched by NASA. Launches used Atlas-Centaur, Atlas F, Scout, and Titan III vehicles.

Space Shuttle. The successful demonstration of the Space Shuttle in its second flight inaugurated a new era in space operations—the era of reusable launch vehicles. After two more test flights, the Space Shuttle, developed under NASA responsibility, is scheduled to begin operational flights in September 1982. At its full performance, the Shuttle will be able to launch 29 500 kg into low-inclination orbits from Kennedy Space Center (by early 1985) and 15 000 kg into high-inclination orbits from Vandenberg Air Force Base (by late 1985). This weight capacity and the larger payload-bay volume (4.6-meter diameter by 18 meters long) will permit a wide variety of payloads to be carried—including multiple payloads in one launch. The payload capacity coupled with the routine and continuing presence of man in orbit will greatly expand DoD abilities and opportunities in space.

In the past, payloads worth tens of millions of dollars have been lost when post-launch malfunctions

could not be rectified by redundant systems on board or by commands from ground control centers. In situations ranging from catastrophic failure to the normal exhaustion of propellants or power, the satellites have been lost. The Shuttle will provide additional options. The operability of a spacecraft can be reconfirmed after launch and before it is deployed from the Shuttle. Malfunctioning spacecraft that are within reach of the Shuttle can be repaired in orbit or returned to earth for more extensive work. Spacelab, the modular laboratory developed by our European partners to fly in the Shuttle, will permit routine, repetitive experimentation and subsystem testing in space.

Most important, the Space Shuttle is the first step toward future routine operations in space. Over the next few years, it will become the workhorse for space, and emphasis will shift from developing a means to get into space toward the many activities we need to pursue in space.

Space Vehicle Subsystems. The Air Force continued to develop advanced guidance, navigation, power, and propulsion subsystems for further space programs. The space sextant, providing autonomous navigation and attitude reference, will be test-flown on the Space Shuttle orbiter in 1982. A complementary strapdown, multimission, autonomous, navigation and attitude-determination (MADAN) system also was being developed. Efforts in power systems include development of high-efficiency, radiation-hardened, solar cells and high-density, metal-gas battery cells. Future efforts will integrate and test the solar cells in large panels and the metal-gas cells in higher density batteries. A pulsed plasma thruster has been developed to provide propulsion for station-keeping of synchronous communications satellites. Spaceflight testing of the pulsed plasma thruster was planned for the near future. A military space systems technology model was being developed to provide a graphic method for determining future needs and for tracking progress toward goals.

Cryogenic-Infrared-Radiance Instrumentation for Shuttle (CIRRIS). The CIRRIS program examined earth-limb and atmospheric backgrounds for an increasing number of applications using infrared technology, as well as studying a number of Shuttle payload contamination issues. In 1981 the CIRRIS payload was integrated with the experiment support system, a platform to provide power and other housekeeping functions for experimental payloads.

Inertial Upper Stage. The DoD-developed, solid-propellant, two-stage IUS—to be deployed from the Shuttle orbiter into low earth orbit—will be used primarily to boost DoD and NASA payloads into geosynchronous orbits. Development was proceeding on a schedule for 1982 launch from the Titan launch vehicle and an early 1983 launch of the first Tracking and Data Relay Satellite from the Space Shuttle.

Centaur. The Centaur upper stage was being

studied for potential use with the Space Transportation System for planetary and heavier geosynchronous missions beginning in early 1985. Preliminary designs would increase the size of the propellant tanks to add 50 percent more capacity (Wide-Body Centaur) and to make the stage compatible with the Shuttle.

Spinning Solid Upper Stage (SSUS). The SSUS was being developed to launch smaller spacecraft from the Shuttle into geosynchronous-transfer orbit. One version, the SSUS-D, can be used on both the Shuttle and the Delta expendable launch vehicle. In 1981, the SSUS-D on the Delta launched two satellites: *RCA Satcom 3-R* and *Satellite Business Systems' SBS 1*.

Spacecraft Charging Technology. The Air Force Space Test Program's Spacecraft Charging at High Altitude (*Scatha*, launched into orbit in 1979) continued to produce relevant data on spacecraft electrical charging. In 1981, significant correlation was noted between solar events, such as flares, and events recorded by *Scatha* instruments.

Space Support

Eastern Space and Missile Center (ESMC). During 1981, ESMC conducted 41 major test operations to support launches and data acquisition in DoD space and ballistic-missile operations, NASA space programs, and commercial and international satellite launches under NASA sponsorship. The ESMC range control center directed DoD radar-tracking-network support of the Space Shuttle during the April and November orbital flight tests.

Western Space and Missile Center (WSMC). WSMC provides range-tracking, data-acquisition, and flight-safety support for DoD ballistic-missile and NASA and DoD space launches, as well as aeronautical tests at Vandenberg AFB. Some 52 major test operations were conducted during 1981. Cruise missile programs dominated the aeronautical testing. Construction of the Space Shuttle Launch Control Center and MX Integrated Test Facility was completed during 1981.

Satellite Control Facility (SCF). The Air Force's network of seven remote tracking sites and the Satellite Test Center (STC) at Sunnyvale, California, control DoD's orbiting spacecraft. During 1981, the SCF supported 11 launches, including 7 DoD orbital missions, 2 NASA orbital missions, and 1 ballistic flight test. It made 86 137 contacts totaling 72 428 hours of support in DoD satellite programs. The production contract in the data-system modernization project was awarded in December 1980, with operations to begin in early 1985. This project will centralize data processing at the Satellite Test Center, reducing operating costs of the remote tracking sites and increasing network capability. SCF supported the November 1981 orbital flight of the Shuttle, providing Indian Ocean coverage from the tracking station in the Seychelles.

Consolidated Space Operations Center (CSOC). CSOC will augment satellite control operations of the Satellite Test Center and provide dedicated DoD Shuttle-control capability. CSOC will eliminate dependence on single critical control elements for both satellites and Shuttle and provide the management and control needed for military space operations after 1986. During 1981, the environmental impact analysis was completed, and Colorado Springs was selected as the CSOC site. Designing began, and construction was scheduled to begin in 1983.

White Sands Missile Range (WSMR). White Sands supported DoD and NASA aeronautics and space programs, including the Space Shuttle, upper atmospheric sounding by rockets and balloons, and astronomical test programs. Launch, flight, and recovery services included both ground and flight safety, range surveillance, command and control, and data acquisition and analysis. Space Shuttle activities at WSMR included qualification tests of the orbital maneuvering system and forward and aft reaction control systems, evaluation of Shuttle spacecraft materials, training of astronauts to land the Shuttle, preparation of a satellite system to track and relay Shuttle data back to the earth, and Shuttle flight support. The range continued preparation for Shuttle landings, including training chase-aircraft pilots and testing tracking acquisition, data transmission, and support systems.

Kwajalein Missile Range (KMR). The Kwajalein Missile Range, operated by the U.S. Army, is the major test range for U.S. strategic missile forces, both offensive and defensive. With the MX advanced intercontinental ballistic missile approaching testing and the pace increasing in the development of ballistic-missile defense, activity at KMR is expected to increase significantly. The facility collects signature data on objects outside the atmosphere, records missile reentry when required, and transmits near-real-time data to mission sponsors. Data collected on missiles fired into the range meet needs of both the strategic offensive and defensive communities. The result is the mutual accomplishment of test objectives and continuous interchange of data among all developmental programs.

Arnold Engineering Development Center (AEDC). AEDC provides facilities for testing developmental aeronautical and space systems in support of virtually every major U.S. aerospace program. More than 50 000 test hours were accumulated in the various test cells in support of projects such as the MX missile, advanced ballistic reentry system (ABRES), advanced surveillance devices, cruise missiles, air-launched missiles, and Space Shuttle.

4950th Test Wing. The 4950th Test Wing, an Air Force Systems Command unit based at Wright-Patterson AFB, Ohio, continued to support national space testing programs. The advanced range-

instrumentation aircraft (ARIA) provided most of this support. Programs supported in 1981 or scheduled for support included the MX, Trident, Space Shuttle, Global Positioning System, Defense Meteorological Satellite, and airborne space-laser communication system. A modernization program was in progress to replace outdated, unreliable equipment and install more modern tracking, data-acquisition, and related equipment.

Aeronautical Activities

Helicopter Programs

Advanced Attack Helicopter (AAH). Full-scale engineering development continued on the advanced attack helicopter in 1981, with emphasis on integrating and testing the subsystems. The Army's operational test II at Fort Hunter-Liggett, California, June-August 1981, assessed operational effectiveness, reliability, availability, maintainability, supportability, and survivability. The test also evaluated deployment capability and adequacy of the training programs. Army personnel conducted the test in three phases: force-on-force tests with near-real-time casualty assessment; firing of Hellfire missiles, 30 mm cannon, and 70 mm rockets; and side experiments. The Army was preparing for a production decision in March 1982.

CH-47 Modernization. Engineering development for CH-47 modernization began in 1976 to give the Army a medium-lift helicopter beyond the year 2000. Three prototype CH-47D models incorporate eight modernized systems: rotor, drive, engines, hydraulic, electrical, advanced-flight-control, cargo-handling, and an auxiliary power unit. These changes should improve performance, maintenance, and safety; reduce vulnerability; and produce one standard CH-47 configuration, facilitating logistics and maintenance. The first production contract for nine helicopters was signed in late 1980. By the end of 1981, two CH-47D prototypes had flown more than 1740 hours of testing. A 1982 contract was planned for modernization of the next 19 helicopters. Modernization of the entire fleet of 436 CH-47A, B, and C helicopters was planned, and the first complete unit of 24 CH-47D helicopters was to enter service in early 1984.

UH-60 Black Hawk. In 1976, Sikorsky Aircraft was awarded the first production contract for the Army's Black Hawk helicopter, and General Electric was given the contract for the engine. By the end of 1981, 337 UH-60As had been placed on contract and the Army had accepted 191. The Black Hawk was in service with the 101st Airborne Division (Airmobile) at Fort Campbell, Kentucky, and other high-priority Army Forces Command units. It can carry a combat-equipped squad of 11 men, or comparable cargo, in all weather,

day or night, in all operational environments. It has met all user requirements in the field.

The Air Force has decided to modernize its combat helicopter fleet with a derivative of the Army's Black Hawk. The aircraft, to be designated the HH-60D, will have extended range and the capability for operations at night and in adverse weather. Full-scale development was scheduled to begin in 1982 with first deliveries in 1986.

Cobra/TOW. Modification of existing Cobra helicopters and purchase of new aircraft with the highly effective tube-launched, optically tracked, wire-guided (TOW) missile, continued. Deliveries of the retrofitted Cobra helicopters, begun in June 1975, will be completed in February 1984. Upgraded engine, transmission, and dynamic components to improve maneuverability were incorporated in new aircraft starting with deliveries in March 1977. The Army planned to upgrade the secondary armament and survivability of the Cobra/TOW to a fully modernized AH-1S helicopter. The modernization program also includes addition of forward-looking infrared (FLIR) to its TOW missile system and making that system capable of firing all three kinds of TOW missile.

Advanced Digital-Optical Control System (ADOCS). The ADOCS will increase mission effectiveness of Army helicopters while reducing cost and weight. Redundant digital-optical hardware will provide protection on the battlefield from ballistic weapons, lightning, electromagnetic pulse, and nuclear radiation. Optics, immune to electrical interference, will provide protection even with the newer composite structures that offer only limited electrical shielding.

Since 1979, the program has developed components and technology for a 1984 flight-demonstration program. Two control media-mechanization programs were completed in 1981, providing data on optimum control media paths and information on additional testing necessary to ensure safe use. Six digital-optical transducer programs begun in 1980 completed design and entered fabrication. Design data will be available to the ADOCS flight-demonstration contractor for preliminary system design. Fabrication of the optical servovalve began. A 24-month contract for the advanced controller and advanced flight control system (AFCS) was awarded in late 1980. During 1981, initial literature review, analyses, and simulations were completed. A 15-month contract for an advanced rotor-actuation concept was awarded in late 1980. All technical work under this contract was completed in 1981 and includes preliminary designs of small and medium-size helicopter rotor-actuation concepts. The ADOCS flight-demonstration contract was awarded in late 1981, with a planned 52-month period of performance.

Fixed-Wing Programs

Remotely Piloted Vehicles (RPV). First flight of the Army's remotely piloted vehicle was scheduled for mid-1982. The RPV will perform target-acquisition, laser-designation, aerial-reconnaissance, and artillery-adjustment missions. The small, unmanned air vehicle and its mission payload are controlled from a ground station, and video imagery and target-location information are returned via a jam-resistant data link. A contract awarded Lockheed Missiles and Space Company in 1979 for full-scale engineering development calls for 22 vehicles, 18 mission payload subsystems, 4 ground control stations, and 3 launcher and 3 recovery subsystems.

Advanced Fighter Technology Integration (AFTI). The Air Force AFTI program completed modification of an F-16 aircraft in 1981. The test aircraft integrates a triple-redundant, digital flight-control system with canard control surfaces to achieve independent six-degree-of-freedom control, improving agility and flexibility. During later phases of the program, the advanced system will be integrated with a fire control system to achieve highly accurate maneuvering attack capability. Technology demonstrated in the AFTI program will be used to improve the performance of future fighter aircraft.

Forward Swept Wing. A joint DARPA-USAF demonstration program was begun in 1981 to design, build, and flight-test an experimental aircraft with a forward swept wing. The program will demonstrate the feasibility of using advanced composite materials to control wing bending in this configuration. The theoretical advantages include reduced transonic drag and increased lift at high angles of attack. The program will investigate these potential advantages and will further define engineering considerations.

Transport Aircraft. Douglas Aircraft Company was selected as the prime contractor for the C-17. This aircraft will be capable of transporting the outsize equipment of a modern army over intercontinental ranges directly into austere airfields in the deployment area. Full-scale development was being considered for early 1982.

Air-Launched Cruise Missile (ALCM). The ALCM is a key element in the U.S. bomber force. It provides greater weapon accuracy, flexible routing and targeting, reduced exposure to enemy defenses, and saturation of defenses. Initially, B-52G aircraft will carry 12 ALCMs loaded on two external pylons, while retaining the capability to deliver internally carried short-range attack missiles and gravity weapons through 1986.

Beginning in 1986, ALCMs will be loaded externally on B-52H aircraft, and still later plans include internal loading of cruise missiles on the B-52Hs for a total of 20 missiles each. The B-1B and the advanced-

technology bomber will also be capable of carrying the cruise missiles.

At the end of 1981, the ALCM program was concurrently in full production, final development, and follow-on operational test and evaluation. A total of 705 ALCMs were under contract in 1981. A 1982 contract for 440 missiles was in review, and a 20-flight test program that began in June 1980 was scheduled for completion in mid-1982. The capability to put the first modified B-52G aircraft on alert with external ALCMs was achieved in September 1981 at Griffiss AFB, New York. Initial operational capability of an entire B-52G squadron, with each aircraft equipped with 12 external ALCMs, was scheduled for December 1982.

Bomber Development. On 8 September 1980, Congress directed the Department of Defense to pursue full-scale engineering development of a multirole bomber, maximizing range, payload, and the ability to perform both tactical and strategic missions of a conventional bomber, cruise-missile launch platform, and nuclear-weapon delivery system.

On 2 October 1981, President Reagan announced his new strategic program, which included a comprehensive plan to modernize the bomber force. This plan will deploy 100 B-1 variants (B-1Bs), with an initial operational capability in 1986. Concurrent with deployment of the B-1Bs will be a research and development program designed to deploy advanced-technology bombers (ATBs) in the early 1990s. The previous administration had planned to rely on B-52s throughout the 1980s and to deploy the ATB in the 1990s. The present administration believes that the B-1B is necessary to bolster the strategic forces during the 1980s and 1990s, and the ATB is needed to provide high confidence that U.S. bombers will be able to penetrate enemy air defenses into the next century.

The new B-1B will provide additional force during a period when the United States must depend heavily on bombers while taking steps to strengthen land-based missiles. The aircraft is expected to be able to penetrate enemy defenses well into the 1990s; later, when the B-52's ability as a cruise-missile carrier becomes questionable and as new ATBs enter the force in numbers, the B-1Bs can carry a greater share of the cruise missiles, eventually replacing the B-52s in this role. The B-1B will then serve as a standoff cruise-missile carrier and conventional bomber well into the next century.

This time-phased modernization program permits orderly development of an advanced technology bomber. The ATB is now in the very early stages of design and concept development. The technologies are promising, but the major advances required indicate that concentrating solely on an ATB would entail high risk. However, the ATB will serve as an essential element of a mixed force of penetrating bombers and cruise missiles sufficient to deter an enemy

through the 1990s and into the next century. The ATB will be needed to supplement the B-1 force in the early 1990s to ensure continuing capability against heavily defended, mobile or superhardened targets. A mixed force of this nature will permit a wide variety of tactical actions and present a difficult problem to a sophisticated enemy defense.

Aeronautical Research

Circulation Control Rotor. Redesign and engineering to correct control problems in the circulation-control rotorcraft being developed by the Navy continued during 1981. The rotor's potential increased hover-lift capability should significantly increase cargo or troop lift capacity for vertical replenishment and marine assault. Basically a shaft-driven rotor system with boundary-layer control, it employs a unique air-blowing technique. Tangential blowing through a hollow blade over a rounded trailing edge generates high lift, and blowing modulation provides cyclic control and higher harmonic control, eliminating many conventional helicopter components. Whirl-tower tests have demonstrated a lift capability of more than 7700 kilograms on the 13.5-meter-diameter rotor. Wind-tunnel tests at NASA's Ames Research Center showed the rotor capable of trimmed flight of 260 kilometers per hour. The first hover flight was made in September 1979.

Synthetic Flight Training. The Army negotiated a multiyear production contract in April 1981 for five flight simulators for the Army AH-1 helicopter, with deliveries scheduled through 1984. Providing realistic visual display by closed-circuit TV and a three-dimensional terrain-model board, it is the first Army simulator for both qualification of aerial weapons and proficiency training. A prototype was in use at Fort Rucker, Alabama, in 1980 and 1981.

Developmental and operational testing of the Army's prototype flight simulator for the UH-60A Black Hawk helicopter continued in 1981. One of the prototype's two cockpit training stations uses closed-circuit TV and the other, computer images. Computer-image generation will be evaluated in operational testing to determine the best visionics for the final production unit.

The Army's CH-47 simulator program was proceeding on schedule. A multiyear contract provides for an initial purchase of three production CH-47C models and an option for two CH-47D simulators. The first production model completed in-plant acceptance testing in November 1981; it was expected to be ready for use at Fort Campbell, Kentucky, by June 1982.

Air Mobility Research Program. The Army does basic research in the aerodynamics of rotor systems, rotary wing and V/STOL aircraft, and advanced propulsion systems, as well as developing materials, structures, and aviation electronics for future aircraft.

Noteworthy achievements in 1981 were made in aeromechanics, propulsion, structures, mathematics, and electronics. Four composite components (baggage door, forward fairing, litter door, and vertical fin) were installed on a testbed helicopter for high-flight-time service evaluation.

Aeronautical Technology Program. The Army also carries out exploratory development and expands scientific knowledge in aeronautical technology. It exploits this knowledge to increase operational effectiveness of helicopters, reduce life-cycle costs, decrease dependence on mechanical components, and improve helicopter-analysis system integration and flight simulation, using both in-house and contract research. In 1981, simulator studies of control-display interaction continued, with emphasis on control system aids for possible application to attack helicopter tasks, including hover and bob-up performance. The program studied effects of engine response on helicopter handling, completed the aeroelastic analysis of an elastic-gimbal rotor system, and designed and tested the major joint and attachments on an all-composite helicopter. Research began on a high-pressure-ratio compressor and a supersonic turbine and continued on adaptive fuel control to improve aircraft handling. Studies determined optimum combinations of centrifugal and axial compressors for a range of airflows and pressure ratios. A program established the feasibility of a helicopter-mounted smoke-aerosol system to counter visual rangefinders.

Flight-demonstration hardware for simplified cargo handling was designed and fabricated. Some 2000 advanced design concepts for helicopter improvements were evaluated. Abrasion-resistant coatings for windshields showed significant improvements. Battle-damage repair methods were identified for structures. Development of a new diagnostics method, LOGMOD, was completed. An ice-phobic coating for main and tail rotors was flight-tested. Architectural design began for the second-generation, comprehensive, helicopter analysis system (2GCHAS). New software and apparatus for man-machine research were also developed. Development of SPURS-A, a hybrid analog computer and program for rotor mathematical modeling, continued.

Avionics. In 1981, the Small Business Administration released the entire nap-of-the-earth (NOE) program from its pilot program. NOE was to develop technology to permit automated, low-level, terrain-following flight. The Army's Communications Electronics Command (CECOM) resolicited contractors for the program and will announce the contract award by mid-1982. In addition, advanced development work continued on the joint tactical microwave landing system, toward production of hardware for flight testing by all three services in 1982. Finally, integrating of overall aircraft electronic systems continued. Field testing was completed on integrated

avionics controls within the cockpit. Analysis of ways to combine engine and airframe sensors was under way, as well as interface studies to permit avionics to use a lightweight data-bus system in place of individually dedicated copper wires. These projects should eventually provide lighter weight, lower cost aircraft electronics that are less susceptible to combat damage.

Advanced Composite Airframe Program (ACAP). The objective of ACAP is to develop and demonstrate helicopter airframes made of composite materials that will reduce weight by 22 percent and cost by 17 percent, reduce radar cross-section, improve crashworthiness, reduce maintenance, and lengthen life. The program aims to establish industry and Army confidence in composites for primary airframe structures, leading toward the early introduction of composite structures into operational helicopters. Resulting technology will be applicable to all future Army aircraft systems as well as the present helicopter fleet.

Preliminary design work by Kaman, Sikorsky, Bell, Hughes, and Boeing Vertol was completed in May 1980. Contracts for phase I (detailed design and full-scale fabrication) with an option for phase II (laboratory tests and flight demonstration) were awarded to Bell and Sikorsky on 31 March 1981. Phase I work began in April, with detailed designs and wind-tunnel tests during the second half of 1981. The tests indicated that the static stability of the airframe was adequate and airframe and landing-gear drag was close to that predicted.

Relations with NASA

Aeronautics and Astronautics Coordinating Board

The Aeronautics and Astronautics Coordinating Board (AACB) deals with major policy issues of mutual DoD and NASA interest. During 1981, in addition to continuing activities of the AACB panels, the board reviewed NASA-DoD work toward future alternatives for IUS and Centaur upper stages for the Space Shuttle, reviewed the development status of the Space Transportation System in preparation for the first manned orbital flight in April 1981, and reviewed STS improvements, STS operations, and DoD STS activities. The board also initiated a NASA-DoD study of technology and facility needs to support future DoD aircraft requirements.

Cooperative Programs

Rotor Systems Research Aircraft (RSRA). Two research aircraft—designed for inflight tests of full-scale main rotor systems with two to six blades—continued to serve as “flying wind tunnels” at NASA's Ames Research Center in a joint Army-NASA helicopter research program. The design also permits

addition of fixed wings and thrusting engines to test rotors at speeds up to 555 kilometers per hour. One of the aircraft earlier flew tests as a pure helicopter, as a compound vehicle with thrusting engines, and as a compound vehicle with thrusting engines and lift-augmenting wings.

XV-15 Tilt-Rotor Research. The tilt-rotor research aircraft program continued rapid progress in 1981, testing experimental aircraft that can take off and land like helicopters and can tilt engines and rotors 90° to cruise in flight like conventional aircraft. Aircraft no. 2 (N703NA) was accepted by the government in October 1980 after shakedown tests by the contractor. Government flight testing began with a NASA-Army team at Dryden Flight Research Facility, exploring high-risk areas of the flight envelope. Performance met or exceeded estimates, with no adverse aeroelastic trends noted. Exploration of the flight envelope continued at Ames Research Center from May 1981, as well as studies of aircraft performance in short takeoffs and landings and steep approaches.

Following restoration from wind-tunnel configuration to flightworthy status, aircraft no. 1 (N702NA) began contractor flight tests to check performance against that of aircraft no. 2. Tests with Navy support evaluated downwash and ground wash at a variety of rotor-tip speeds, power levels, and heights from the ground. The tests also obtained data on acoustics and pilot work-load in a precision hover task at various heights.

In the spring, aircraft no. 1 participated in the Paris Air Show, flying demonstrations daily and arousing great interest. The tilt-rotor team also briefed NATO officials. Returned to Ames, the aircraft was back in flight status at the end of 1981. Tests of the XV-15 at Fort Huachuca and Nellis AFB were planned for 1982.

Satellite Communications. NASA and the Air Force were cooperating in a program to develop components and subsystems for satellite communications in the 20- and 30-GHz bands, including solid-state replacements for uplink and downlink repeaters and terminals.

Department of Commerce

Four agencies in the Department of Commerce contribute directly to the nation's aeronautics and space programs: the National Oceanic and Atmospheric Administration (NOAA), the National Bureau of Standards (NBS), the National Telecommunications and Information Administration (NTIA), and the Bureau of the Census (BOC).

NOAA's long-range goal is to improve the safety and quality of life through better understanding of the earth's environment and more efficient use of its resources. NOAA manages and operates the nation's civil, operational, environmental satellite systems. It provides satellite data to assess the effect of natural and human factors on global food and fuel supplies and on environmental quality. It uses satellite and aerial data to observe and forecast weather conditions, issue warnings of severe weather and floods, and assist communities in preparing for weather-related disasters; to prepare charts and coastal maps and for geodetic research; and to assess and conserve marine life. NOAA archives and disseminates satellite data to meet the needs of public and private users and incorporates it into research programs to improve the nation's environmental services.

NBS develops and maintains the national standards of measurement for government, industry, and academia. It provides measurement support services for space systems, atmospheric and space research, and aeronautical programs.

NTIA, the principal communications adviser to the president, develops and coordinates executive branch policy in telecommunications and information. NTIA manages the radio spectrum assigned for federal use, provides technical assistance to federal agencies, and develops telecommunications applications.

BOC uses satellite data to improve information on population trends, urban growth, and the internal structure of national land areas.

Space Systems

Satellite Operations

Polar-Orbiting Satellites. At the beginning of 1981, *Tiros-N* and *Noaa 6* were the active polar-orbiting satellites operated by the National Earth Satellite Service (NESS). After failure of the power supply on

Tiros-N in February, NESS operated a one-polar-satellite system until *Noaa 7*, launched 23 June 1981, became operational on 24 August. *Noaa 6* and 7, in sun-synchronous orbits, provided environmental observations of the entire earth four times each day. *Noaa 6* crosses the equator southward at 7:30 a.m. local time, and *Noaa 7* crosses the equator northward at 2:30 p.m.

These satellites carry four primary instruments: the advanced very-high-resolution radiometer, the *TIROS* operational vertical sounder, the Argos data-collection and platform-location system, and the space environment monitor.

Geostationary Satellites. At the end of 1981, *Goes 4* and 5 were the operational satellites in NOAA's Geostationary Operational Environment Satellite (GOES) system, the successor to NASA's prototype Synchronous Meteorological Satellites (SMS). *Goes 4*, launched in September 1980, replaced *Goes 3* as the western operational satellite on 5 March 1981, because of deterioration of the *Goes 3* visible-infrared spin-scan radiometer (VISSR). *Goes 5* was launched 22 May 1981 and replaced SMS 2 as the eastern satellite 5 August, when the SMS VISSR failed. Of three satellites on standby—SMS 1, *Goes 1*, and *Goes 2*, providing limited operational weather support for weather facsimile and data collection—SMS 1 was deactivated 29 January 1981 after nearly seven years' service. For the first time, a U.S. geostationary satellite was boosted up and out of orbit to alleviate cluttering at the geostationary altitude.

In orbit at 35 000 kilometers, *Goes 4* and 5 are equipped with the VISSR atmospheric sounder (VAS). In addition to the traditional images of the earth's surface and cloud cover, the VAS records atmospheric temperatures and water vapor content at various altitudes. It has a multispectral imaging capability with 12 infrared channels and can derive temperature and moisture data over selected areas. First results of the VAS demonstration program showed promise, and planning was begun for a ground system to use the full VAS capability, to improve operational forecasting. GOES satellites also carry a space environment monitor, a data-collection system, and weather facsimile broadcast service.

Land Satellites. NOAA, directed to prepare for management of an operational land satellite system

based on the Landsat-D and -D' satellites being constructed by NASA, expects to assume operational responsibility for the first of these satellites early in 1983, after NASA has launched and tested Landsat-D. NOAA will operate the two satellites and supporting services for data users until the private sector can take over the land-remote-sensing program. During 1981, NOAA worked with federal agencies and the user community to ensure smooth management of the system and to determine the appropriate institutional framework for private sector takeover.

The Program Board on Civil Operational Land Remote Sensing from Space, established by the secretary of commerce with members from 11 federal agencies and departments, coordinates federal matters related to the operational system. For interested nonfederal groups, the secretary established the Land Remote Sensing Satellite Advisory Committee. Its 15 members will begin regular meetings in 1982, advising on system management and private sector activities.

NOAA conducted five general conferences in 1981 to inform nonfederal interests of plans and to seek advice about system management and future commercialization. It held three other meetings, specifically directed to commercialization questions. NOAA used information from these meetings and others in Africa, Asia, and South America to refine management preparations, to develop recommendations for administration proposals for legislation, and to facilitate planning for the future transfer.

Satellite Data Services

Data Distribution. Images from the European weather satellite *Meteosat 2* were first received by NOAA on 16 September 1981 and became an operational product available to GOES-Tap users during October. These visible, thermal-infrared, and atmospheric water-vapor data provide excellent weather information for aviation and shipping in the eastern Atlantic, Europe, Africa, western Asia, and western Indian Ocean. Received at NASA's Goddard Space Flight Center, the data are relayed directly to NOAA for nationwide distribution.

The GOES-Tap system, which became operational in 1975 to disseminate weather satellite images by geographic sectors over standard telephone circuits, continued to expand. NESS began hardware modifications to permit more than 400 direct GOES-Tap connections through the Satellite Field Services Stations. The original 50 Weather Service Forecast Office-Taps increased by the end of 1981 to some 200 taps for a multitude of users, including the National Weather Service, military facilities, private meteorological firms, TV stations, and universities. Secondary taps off these 200 totaled more than 400.

During 1981, NESS eliminated its last "wet" photographic laboratory, at the Honolulu station.

NESS now uses dry-paper, image-processing devices for satellite image display at all field locations. To reduce operating costs further and increase services, installation of an electronic animation system (EAS) at each field station was begun in 1981; devices were installed in Washington, Miami, and Honolulu during the year. The EAS will provide cloud animation previously provided by movie loops. The microprocessor-controlled, video disc system uses a TV camera to store satellite images sequentially on the disc. Images are played back electronically to display animated cloud motion. Versatility of the EAS permits simultaneous display of two independent "loops" on TV monitors, and meteorologists can control each loop separately for detailed analysis. The first phase of the improvement program—photo lab elimination and animation upgrading—neared completion. Engineering for the second phase, digital transmission of data, began in late 1981. Stations now transmit and receive satellite image data in an analog (facsimile) format. Computer processing and inherent hardware limitations slightly delay the transmission of facsimile images, and they cannot be used for precise quantitative analysis. Digital transmission will provide more timely and quantitative information. A microcomputer system will be developed to transmit digital infrared data in near real-time on the existing communication system, and a similar microcomputer system at field stations will permit more detailed analysis of regional weather and ocean systems.

GOES weather facsimile (WEFAX) broadcast schedules were expanded on both the central and the west GOES satellites, so that 198 satellite sectors and 66 weather charts can be broadcast each day. Some 150 national and international WEFAX users include more than 40 U.S. government stations. During April 1981, the first WEFAX Users Conference was held in Washington, D.C., with 130 attendees including representatives from several foreign meteorological agencies, academia, industry, and amateur radio enthusiasts.

The GOES Data Collection System (DCS) at the end of 1981 had more than 2500 data-collection platforms (a 100-percent increase in the past year) operated by 58 national and international users. There were 13 operational direct-readout stations with 2 more expected to become operational next year. A revised DCS Users Interface Manual reflected major changes put into effect with the automatic monitoring system that keeps watch on the quality of radio performance of the DCS platforms. Also, a major reply-channel realignment will ensure a three-kilohertz separation between channels on the same spacecraft, reducing chances of interference and allocating segments of the frequency bank for specific operations, such as random reporting and interrogation. Improvements in data distribution from the NESS DCS Center at Camp

Springs also included addition of a rotary direct-dial-in system.

On 24 August 1981, NOAA opened its seventh Satellite Field Services Station—at Slidell, Louisiana—and began 24-hour satellite observation of the Gulf Coast and the Gulf of Mexico weather and ocean conditions. The new station, colocated with the National Weather Service Forecast Office, will assist NWS in expanding forecasting and warning services for coastal and offshore areas from Mexico to Florida. Special attention will be paid to conditions affecting small craft and helicopter traffic supporting offshore oil platforms.

The Environmental Data and Information Service (EDIS) completed a functional design for an electronic catalog service. Implementation of the basic system was planned for late 1982, to provide elements of the U.S. climate program a comprehensive catalog of satellite data and products. A computerized interactive service with remote access (supplemented by hard copy) will provide "one-stop" service for information about the availability, characteristics, and source of data and products from all satellite data archives. Ultimately the user will be able to place an order electronically.

In 1981 EDIS also completed studies and began procurement for a system to collect and store full-resolution GOES digital data, produce statistical summaries, and provide photographic and digital data or summary products by late 1982 or early 1983. Meanwhile, the University of Wisconsin was archiving these data for the period beginning with the first GARP Global Experiment (December 1978) until the new system is operating.

Data Support. EDIS provided central information exchange, archival, and data-dissemination services for the international Solar Maximum Year program during 1981. It also provided preliminary information exchange and participated in planning for the Middle Atmosphere Program scheduled for 1982 to 1985.

Using energetic particle data from the *Tiros-N* and *Noaa 6* satellites, EDIS developed a computer program to identify the equatorward boundary of the auroral oval. The results will support tests of a new U.S. Air Force over-the-horizon radar system. Precipitation estimates from *Tiros-N* and GOES satellite images supported the Agency for International Development's disaster assistance effort, in evaluation of weather effects on crops in developing nations. During 1981, EDIS provided weather data to 50 countries in Africa, and also to Central and South America and Asia.

National Weather Service support to the 1981 Space Shuttle flights was aided by GOES satellite images, particularly in monitoring weather conditions near preselected recovery sites around the world. Weather criteria for recovery or landing were stringent, and the

high-resolution images provided information not available from other sources.

NWS also established special ocean service units in New Orleans and Washington to expand services to the marine community. Satellite data will be used to monitor sea surface temperatures, ocean color changes, ocean current intensity and migration, sea ice and sea fog, sea state, and other factors affecting fishing, marine transportation, offshore drilling, and other marine activities.

In 1981, NOAA began to plan experiments and tests for a variety of techniques for weather forecasting and warnings using data obtained from the VISSR atmospheric sounder (VAS) on the *Goes 4* and 5 satellites. The capability of these instruments to monitor variations of atmospheric temperature and moisture was demonstrated. During September and October 1981, a hurricane research support operation used GOES-East (at 75° west longitude). Eight 30-minute atmospheric temperature soundings over Atlantic hurricanes were made each day. Also, the GOES-West (135°W) satellite produced two water vapor images each day. These images were available to users through the GOES-Tap, and moisture images were used to locate high-altitude low-pressure areas and jet streams. These atmospheric temperature and moisture profiles are expected to improve central guidance products, severe local storm forecasting, tropical storm analysis and forecasting, and mesoscale weather event detection. Additionally, the VAS has the potential to improve sea surface temperature measurements and forecasts of clear-air turbulence, thunderstorm formation, and minimum temperatures.

In 1980, NASA and NOAA demonstrated a Centralized Storm Information System in the operational environment of the National Severe Storms Forecast Center in Kansas City. During 1981, preliminary evaluation was completed. The system is designed to increase flexibility in displaying satellite data and superimposing conventional meteorological information on the satellite images. The new technology provided field forecasters with improved mesoscale analyses and guidance. Satellite interpretation messages discussed phenomena such as rapidly developing thunderstorms, intersecting small-scale boundaries where convection often develops, and low-level wind-shear boundaries. In addition, greater emphasis was placed on weather situations that affect aircraft operations, such as areas where fog and stratus are forming, moving, and dissipating and areas of adverse winds aloft. Rapidly transmitted information permitted air controllers to assess pending air-traffic problems better and to improve terminal forecasts.

During 1981, NOAA supported several climate research programs using the Argos data-collection and platform-location system on NOAA satellites to

monitor and track drifting buoys. The Argos system offers precise platform-location data (within 5 kilometers), critical for investigating ocean currents and ice-field movement, and affords reliable and economical data collection from remotely deployed surface and subsurface sensors. More than 75 buoys collected oceanographic, meteorological, and location data to support several studies: The Equatorial Pacific Ocean Climate Studies (EPOCS) are testing the hypothesis that interannual variability of the equatorial sea surface temperature is a fundamental driving force for interannual atmospheric variability. The Arctic Basin Buoy Program was designed to measure and archive data on fields of pressure, temperature, and ice velocity and their year-to-year variations; determine relationships between atmospheric variables and ice behavior; determine ice export from the basin; and improve real-time high-latitude pressure maps and forecasts of weather and ice conditions. The Observations of the Equatorial Surface Jet program examines the spatial extent of the equatorial surface jet stream in the Indian Ocean, using drifting buoys deployed at regular intervals.

Satellite Data Uses

Winds and Temperatures. NESS studies demonstrated that satellite sounding data can depict the horizontal and vertical temperature structure of the atmosphere in both tropical and extratropical regions. The temperature structure, associated with the low-level jet stream over the eastern Atlantic Ocean and western Africa, was established using only satellite data and vertical cross-sections in mid-latitude frontal zones; results compared closely to those determined from radiosonde measurements. Also, a joint experiment was begun with the Israel Meteorological Service and Tel Aviv University to evaluate the effects of satellite soundings and cloud-vector winds on operational numerical weather forecasting models.

During three weeks of March 1981, in Denver, simultaneous radiometric and radar data from the NOAA Wave Propagation Laboratory's ground-based profiler were processed to yield vertical temperature profiles for comparison with profiles derived from the *Noaa 6* satellite. Except within about 1500 meters of the earth's surface, where the satellite measurements are poor, the ground-based and satellite profile agreed to within 2°C.

The hardware feasibility study of a Space Shuttle-launched *Windsat*, a satellite to measure global winds with an onboard, pulsed-doppler lidar (laser light detection and ranging), was extended to include experiments in detecting water vapor, temperature, aerosols, and atmospheric constituents. With only minor changes, the *Windsat* feasibility experiment accommodated a number of experiments originally pro-

posed for other lasers. An analysis of the preliminary design of *Windsat* showed that it could perform with a satellite weight of less than 1000 kilograms and power less than one kilowatt.

NESS developed an objective analysis technique to measure low-level winds around hurricanes from cloud motions derived from geostationary satellite images. The satellite-derived measurements compared favorably with wind measurements by NOAA reconnaissance aircraft.

During 1981, alternatives for deriving high-altitude wind measurements were evaluated to replace the costly film-loop method, which requires expensive photo processing. The two methods tested were an automatic computer-generated product and an interactive-computer method controlled by a meteorologist. Although testing and evaluation are not complete, NESS began using the interactive method in late 1981, to benefit from the cost savings until the testing was completed.

High-resolution multispectral data, obtained from the *Noaa 6* and 7 advanced very-high-resolution radiometers, were used to test new methods for measuring sea surface temperatures globally from space. Preliminary results indicated that significant improvements could be made and that more high-quality temperature measurements were being obtained than with the method already in use. Operational use of the new technique began in November 1981.

A sea-surface-temperature composite chart, using visible and infrared digital data from GOES satellites, was made operational during 1981. The composite uses digital data at different observation times to form a more cloud-free sea-surface field of thermal-infrared temperatures. The composite field is used mainly for detecting ocean thermal fronts and eddies, and their movements, in high-gradient ocean and coastal zone areas of the United States. It is produced once a day for preselected areas of the coastal zone.

Global Radiation. NESS research made considerable progress in the *Nimbus 7* Earth Radiation Budget program. Two complete years of solar data have yielded a mean solar constant of 1375.6 watts per square meter with a standard deviation of 0.97 watts per sq m. Variations exceeding 0.2 percent over five to seven days were observed and were independently verified by an instrument on the *Solar Maximum Mission* satellite. A preliminary set of models for the angular distribution of reflected and emitted radiation appears to be an improvement on existing models.

A 67-month data set comprising mean monthly radiation budget estimates (albedo, outgoing radiation, absorbed solar energy) was extended with *Noaa 6* and 7 data. These data have been extensively used by the Climate Analysis Center in diagnosing climatic conditions and by NESS in studying the radiation balance during the first GARP global experiment.

Environmental Warning. NOAA's National Hurricane Research Laboratory (NHRL) continued to use satellite and other remote-sensing data to support its hurricane research. Aircraft-borne microwave instruments measured wind speeds in Hurricane Greta and Ella in 1978, and measurements were compared with *Seasat* scatterometer-derived figures. *Seasat*-derived winds were mostly within 10 percent of the aircraft-measured winds. The exception was near the region of maximum winds, where *Seasat* underestimated aircraft-measured winds by 20 percent because of poor spatial resolution. In a similar experiment during Hurricane Allen in 1980, satellite-derived winds were within 10 percent of the aircraft-measured winds up to 240 kilometers per hour and were of high spatial resolution—demonstrating that hurricane-force winds can be remotely measured.

NESS studied satellite images to improve warning services. The Miami Satellite Field Services Station continued to monitor Atlantic Ocean hurricanes for the NWS National Hurricane Center. The locations and maximum sustained winds for all hurricanes and other tropical disturbances were determined from satellite data, which were often the only information available. Hurricanes were located with an average accuracy of 32 km, and maximum sustained winds were estimated with an average accuracy of 18.5 km per hour. Center forecasters prepared advisories for the public, marine, and military interests. Similar information is provided by the San Francisco station for the eastern Pacific Ocean, by the Honolulu station for the central Pacific Ocean, and by NESS's Synoptic Analysis Branch for the western Pacific and Indian Oceans.

In support of NHRL's study to detect large cumulonimbus clouds called "supercells," NHRL used rapid-scan images from the GOES-East satellite to document the evolution and structure of these cells in developing tropical storms. The satellite images permitted interpretation of simultaneously obtained aircraft measurements.

Using GOES digital infrared images in other research, NOAA's Office of Weather Research and Modification estimated rainfall from convective clouds over the central United States for one month. The technique was tested under mesoscale conditions to develop streamflow models. Satellite rain estimates compared favorably with rain-gauge and radar data. NASA and NOAA investigated the Florida sea-breeze regime. Rainfall computed for six study days showed that the rainfall patterns of the convergence zones in a sea-breeze model were similar to rainfall estimates from the satellite data.

NESS now routinely uses GOES images to estimate the amount of rainfall from thunderstorms, helping meteorologists and hydrologists predict floods. During 1981, NESS experimentally modified the technique to take into account unusual or more-difficult-to-predict thunderstorms—those occurring in dry environments,

with high bases, or with warm tops. NESS also developed several automated experiments that use GOES data to analyze precipitation from tropical and extratropical storms, and improved techniques to estimate precipitation from enhanced nonconvective cloud images, for more accurate predictions in the western United States. Precipitation estimates were also attempted for the first time on winter storms along the West Coast.

NESS improved its operational satellite support to the National Weather Service Flash Flood Program by acquisition of the interactive flash-flood analyzer, to replace the time-consuming manual method of determining precipitation amounts from GOES data. The more rapid, more accurate analyzer can also disseminate products to NWS and other users simultaneously—a significant improvement, as flash floods occur with little advance warning, endangering lives and property. It is scheduled to become fully operational by 1 March 1983, replacing the costly photographic medium by cheaper, computer-driven, electronic data-display and analysis.

The Prototype Regional Observing and Forecasting Service continued to test techniques combining satellite, radar, and surface observations and ground-based atmospheric sounding data for improved short-term (up to 12-hour) metropolitan-area forecasts. First applications to severe storms and flash-flood warnings, using data collected during the spring and summer of 1981, showed great promise.

Satellite data aided fire fighters in the western United States and Alaska. "Hot spots" were found to be detectable by comparing bands three and four of the advanced very-high-resolution radiometer carried on *Noaa 6* and 7. Images from these two bands were used to find forest fires, active volcanoes, and waste-gas flows from oil wells and steel plants.

The eruption of the Pavlof and the Shishaldin volcanoes in the Aleutians in September 1981 was first discovered by meteorologists at the Anchorage field station. Information about ash plume height, movement, and area coverage was provided to the U.S. Geological Survey and the Federal Aviation Administration Air Route Traffic Control Center. NESS also provided the Smithsonian Scientific Event Alert Network with timely information on new eruptions. The satellite data often are the first or only information the Smithsonian receives on eruptions.

During 1981, the U.S. Navy-NOAA Ice Center provided special satellite analyses of ice conditions to the U.S. Coast Guard for the visit of the ice breaker *Polar Sea* to Alaska's north slope. Satellite ice observations also remained important in the U.S. Fish and Wildlife Service's study of the migration of marine mammals (walrus, whales, seals, and polar bears). Further satellite studies of ice patterns in Cook Inlet suggest a two-year light-ice and heavy-ice cycle. This information is particularly important for engineering and con-

structing dock facilities for transportation of coal from Alaska.

Devastating downslope winds have hit Anchorage, Alaska, half a dozen times in the last two years, causing more than \$50 million worth of property damage. Studies of satellite and conventional data for these events have led to development of a technique that uses satellite images to alert National Weather Service forecasters of potential high-wind situations 24 hours in advance.

The Miami station expanded support to commercial fishermen and marine shippers by making available via automatic telecopier its regional analyses of thermal fronts defining the location of the Gulf of Mexico Loop Current and the Gulf Stream between Cape Hatteras and the central Gulf of Mexico. These analyses, prepared three times each week, now are widely used by marine shipping companies, who report fuel savings of as much as \$8000 per day per ship. Large savings in fuel and time, and much improved catches, have been reported by commercial fishermen, who now go directly to thermal fronts that mark the preferred fishing areas. The information also is broadcast via the NOAA Weather Radio from all NWS Weather Service offices along the Florida coast from Jacksonville to Key West.

Oceanography. NESS conducted several studies of oceanic circulation using satellite infrared measurements. In a joint investigation with the Lamont-Doherty Geophysical Observatory, aided by Argentinean ship hydrographic surveys, a large number of warm-core eddies were found south of the Brazil Current. A survey of currents off the coasts of Australia, made in cooperation with Australia, confirmed earlier hypotheses from biological indicators that a southward-flowing current exists along the western shore; the current turns eastward along the southern coast. In a collaborative study with Texas A&M University, a low-frequency counterclockwise precession of a cold-core Gulf Stream ring was discovered by combining satellite infrared data with hydrographic observations. Analysis of five years of geostationary satellite infrared images showed the recurrence and variability of very long (1000-km wavelength) waves at the eastern equatorial Pacific thermal front. These results are used to test numerical models of ocean circulation.

Analysis of Defense Meteorological Satellite images of the Sulu Sea showed propagation characteristics of large-amplitude, nonlinear internal waves and how they are affected by bathymetry and the earth's rotation. Surface effects of the internal wave field appear as striations in the sunglint pattern. The internal waves occur in packets that originate in the Sulu Archipelago, travel northward over 400 km to Palawan Island, and disappear. They are characterized by wavelengths of 5 to 10 km, crest lengths in excess of 200 km, and phase velocities of 250 cm per second,

making them among the largest and fastest internal waves ever observed. An intensive field experiment in the Sulu Sea examined the generation, propagation, and dissipation mechanisms that govern these waves. Fifteen packets of internal waves were documented with vertical amplitudes of 30 to 100 m and periods of 30 to 55 minutes. Each packet evolved from a broad thermocline depression generated by a tidally induced hydraulic flow over the Pearl Bank sill. The field data supported the interpretation based on satellite images.

Jet Propulsion Laboratory processed data from the 100 days of *Seasat* observations in 1978 to provide the first global maps of mean wind speed and wave height measured from satellites. Some 3.5 million observations were averaged into 2.5°-latitude by 7.5°-longitude areas, demonstrating the potential for providing synoptic-scale, global sea-state information useful to oceanographers, meteorologists, and climatologists.

Global measurements of atmospheric water vapor by the *Seasat* scanning, multichannel, microwave radiometer (SMMR) also were shown. The estimates were used to make path length and attenuation corrections in the active microwave radiometers: the altimeter, which provided estimates of windspeed and significant wave height at nadir; and the scatterometer, which gave estimates of the vector wind field near the surface. Global estimates of water vapor would be useful in climatological studies of the variability of the latent heat of vaporization that is transferred from ocean to the atmosphere.

Sea surface temperatures derived from the *Seasat* SMMR were compared with conventional data observed at the surface. In the tropical Pacific Ocean, the SMMR-derived temperatures were inferior to ship measurements in absolute accuracy, comparable in relative accuracy, and superior in uniformity of spatial coverage. With improved computer programs, the SMMR measurements are expected to be better than those from ships.

NESS processed data from the coastal-zone color scanner on *Nimbus 7* to develop computer programs for deriving phytoplankton pigment in the northwest Atlantic Ocean, where ships collected extensive biological and optical data. Agreement between data from the scanner and from the surface observations was excellent. Development of good atmospheric corrections for the scanner data produced images showing detailed phytoplankton patterns associated with large-scale oceanic features such as currents and warm-core rings.

NOAA's Pacific Marine Environmental Laboratory also compared scanner data over the North Pacific Ocean with shipboard measurements of chlorophyll and particle concentrations. The objective is to use satellite data to monitor ocean productivity and its effect on the carbon dioxide atmosphere-ocean exchange rate.

Hydrology. Snowcover data from 30 western U.S. river basins during the 1980-1981 snow season were given to the Soil Conservation Service, Water and Power Resources Administration, U.S. Army Corps of Engineers, U.S. Forest Service, National Weather Service, Department of Energy, U.S. Geological Survey, and California State Department of Water Resources. More than 600 satellite determinations of snowcover were made between November 1980 and July 1981. Snowpacks were well below average throughout most of this region, reflecting a season-long drought. Automation of snowmapping techniques using the NESS interactive systems was the subject of two pilot test reports released in June 1981. As a result, automated snowmapping for six Rocky Mountain river basins became operational at the Kansas City Satellite Field Services Station 1 December 1981.

During 1981, software was developed to produce a Northern Hemisphere digital snow map by analyzing polar stereographic satellite images on a NESS interactive system. The derived tapes are then sent to the U.S. Department of Agriculture and the Johnson Space Center for early warning of winter wheat kill in high-latitude regions.

Agriculture. Information on global crop production is required for effective response to fluctuations in the world food supply. This information is useful to all sectors of the agricultural community, including individual farmers and ranchers, commodity analysts, agribusiness, and agricultural policy makers.

In the interagency Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing (AgRISTARS; see NASA and Department of Agriculture chapters), NESS is developing products from operational environmental satellite data that will supplement conventional weather observations and improve the accuracy of the Department of Agriculture's forecasts of crop production. During 1981, computer programs were developed to estimate precipitation, solar radiation, maximum and minimum temperatures, snowcover, and vegetative index from satellite data. Plans are to test the programs in an operational environment. Precipitation and solar radiation estimates were delivered to Agriculture on a test basis in 1981.

Since May 1981, NOAA polar-orbiting satellites have been making infrared observations over regions designated by Agriculture's Crop Commodity Assessment Division. The satellite data are used to produce a vegetative index. Coverage varies from one to nine days. On average, four sets of the infrared data are sent each morning to the Johnson Space Center for operational use. The *Noaa 7* satellite, with its high sun-angle afternoon orbit, permits monitoring of high-latitude crops year around. NOAA and NASA are making a priority study of the Nile Delta crop region to develop scan-angle and atmospheric attenuation corrections for the satellite data. The

Agency for International Development, the Central Intelligence Agency, and the United Nations Food and Agriculture Organization also use these data. Additional applications are terrain classification and monitoring of deforestation and the spreading of deserts. Polar-satellite infrared data also provided valuable information on the variation of soil temperatures in the Alaskan interior during the summer.

Fisheries. A weekly, mesoscale, Alaskan sea surface temperature chart, prepared from polar-satellite infrared data, is distributed to some 200 government and private users. Additionally, it is transmitted over the National Weather Service Radiofacsimile Broadcast Service from Kodiak, Alaska, to vessel operators needing information on superstructure icing conditions and to commercial fishermen and fisheries researchers concerned with the arrival of commercial fish in Alaskan waters. Herring arrive at 4°C and red salmon at 7°C in Bristol Bay, silver salmon at 11°-13°C in southeast Alaska, and pink salmon at 11°C near Kodiak Island. The charts save travel time and reduce labor and fuel costs. The information also is used for local fish inventory and migration studies, for fish harvest forecasting, and for environmental impact studies and engineering specifications by oil companies, the Bureau of Land Management Outer Continental Shelf Program Office, and many other groups concerned with oil and gas lease sales.

The National Marine Fisheries Service's first system for satellite data processing and analysis was installed at its Bay St. Louis, Mississippi, facility of the Southeast Fisheries Center in cooperation with NASA. Software, originally designed for Landsat data, was updated to process *Nimbus 7* coastal-zone color scanner, GOES, and NOAA temperature data. The system already has been used in a fisheries study by the University of Michigan and will be used in cooperative studies with the Northeast and Southwest Fisheries Centers, the state of Louisiana, U.S. Fish and Wildlife Service, and NASA.

A study was begun in 1981 to establish relationships between the extent and character of coastal wetland ecosystems and the health and productivity of recreationally and commercially valuable living marine resources. Conducted by the Northeast and Southeast Fisheries Centers, NASA, and the state of Louisiana, the study will use Landsat data to monitor changes in wetland ecosystems in marsh areas of Louisiana.

Operational products were developed using *Seasat* wind data as input to a Gulf of Mexico surface-transport model. Examples are the inventory of available data, the display of wind vectors, and the derivation of wind-induced properties of ocean circulation in the gulf. Model products such as wind-driven currents and transport and upwelling areas are useful for fisheries, particularly in studying the dispersal mechanisms for plankton. Ocean current data

show trajectories and establish times required for passive life stages to drift from one location to another. *Seasat* provided new technology to monitor, model, and predict pathways by which offshore spawn of estuarine-dependent shellfish and finfish find their way into coastal nursery grounds.

During 1982, the Fisheries Services will use ocean color and thermal data from the *Nimbus 7* coastal-zone color scanner. Scanner indications of chlorophyll concentrations combined with temperature data may provide more insight into the large-scale distribution, abundance, and migration patterns of large pelagic fish such as bluefin tuna, billfish, and sharks.

An objective of the Fisheries Service is to achieve a zero net loss of habitat and productivity for critical marine estuaries and anadromous species by 1985. Using Landsat data, the Northeast Fisheries Center developed the Coastal Habitat Assessment and Research program to quantify changes in productivity, biomass, and areas of principal coastal-zone habitats from North Carolina to Maine. The program will proceed in three phases: phase 1 will determine how many acres of wetlands exist and what vegetation types they contain; phase 2 will determine how many acres of wetlands have been lost or gained in the past 10 years; and phase 3 will determine how the value and quality of coastal habitat is changing, from biomass and other properties.

The center also participated with the NASA Langley Research Center in the Nantucket Shoals experiment and in planning the National Science Foundation warm-core-ring studies. The Nantucket Shoals experiment used shipboard, in situ, and aircraft and satellite remote-sensing techniques to investigate the distribution and abundance of phytoplankton on the shoals in relation to rates of nutrient supply, growth, vertical mixing, and advective processes. The warm-core-ring studies seek to understand physical, chemical, and biological processes related to Gulf Stream warm core rings. The Fisheries Service is augmenting this experiment by studying the shelf-slope interface and is building a high-resolution picture transmission system in cooperation with NASA's Goddard Space Flight Center.

The application of satellite observations in marine fisheries research and management was being evaluated in studies at the Southwest Fisheries Center. Using satellite thermal-infrared images and extensive sampling of northern anchovy eggs and adults, one study found that no spawning occurred over large areas off California during the peak spawning period. In this study, only satellite data provided fishery scientists with a synoptic picture of the large-scale oceanographic events over the entire anchovy area during the peak season. Ocean color images from the *Nimbus 7* color scanner assisted in describing habitats for coastal marine mammals in another study. The center also participated in an experimental, satellite-

oriented, observation program for commercial fisheries sponsored by Jet Propulsion Laboratory and the National Weather Service.

Other Uses of Satellites

International Activities

Two foreign governments contribute instruments to the NOAA polar-orbiting satellites. The French National Center for Space Studies provides the Argos satellite data-collection system; the British Meteorological Office provides the stratospheric sounding unit, a component of the TIROS operational vertical sounder. Fourteen countries operate 275 platforms through the Argos system. The majority of the platforms must be periodically replaced, and more than 2000 have been used since its inauguration. The U.S.-funded processing agreement as of 1981 supported 145 platform-years. The telephone communications system at Suitland, Maryland, which allows users direct access to their disc files in Toulouse, France, was being used by 27 subscribers.

Some 120 countries received images and digital data directly from satellites operated by NOAA. Medium-resolution images are received in some 890 locations globally and high-resolution data in 25 countries. Geostationary satellites provide weather facsimile broadcasts to nearly 30 countries in the Western Hemisphere and to Australia and New Zealand; 3 nations other than the United States also received high-resolution images. The GOES Data-Collection System also is used by several countries in the Western Hemisphere for relaying environmental data from remote platforms.

NOAA participates in an informal group known as Coordination on Geostationary Meteorological Satellites (CGMS), through which technical managers planning national geostationary meteorological satellites discuss common interests in design, operation, and use of their spacecraft. The European Space Agency (ESA), Japan, the Soviet Union, and India also participate. There are four operating satellites—two launched by the U.S. and one each by ESA and Japan. While independently designed and developed, they have met common meteorological mission objectives and have produced certain compatible products for worldwide users.

Present and prospective operators of national, land-remote-sensing satellites have established a similar group known as Coordination of Land Observation Satellites. This group—in which NOAA, NASA, and representatives from France and Japan participate—is considering coordination and harmonization of data products, satellite-to-ground telemetry, and spacecraft orbits to ensure maximum compatibility. During 1981, NOAA also coordinated U.S. participation in regional meetings in Africa, Asia, and South America

to inform foreign users of products and services that will be available from the planned land-remote-sensing satellites.

Domestic Activities

During 1981, the Census Bureau completed a NASA-sponsored applications test program evaluating Landsat images as a resource for identifying new development on the periphery of urbanized areas. Landsat image interpretations of five cities were compared with results from aircraft photography. For some test sites, Landsat images depicted the development patterns very clearly; results from other areas were more difficult to interpret. High-resolution images from future spacecraft and other sensor systems will be considered as a possible data source in preparation for future decennial censuses.

Training

In 1981, the NESS Applications Laboratory instructed some 270 persons in satellite image interpretation. Two regional workshops for forecasters were held in Raleigh, North Carolina, and Slidell, Louisiana. Four classes at the National Weather Service Training Center were trained to estimate rainfall amounts from satellite images. In addition, training for Department of Defense meteorologists continued in 1981. Four classes at Offutt Air Force Base used satellite images to observe aviation weather problems and illustrate techniques of severe weather analysis. NESS held one extensive training session for Naval reservists.

Application of Space Technology to Geodesy and Geodynamics

The National Geodetic Survey, a component of the National Ocean Survey, continued to work with NASA to apply space technology to geodesy and geodynamics. Development of a new-generation polar-motion and universal-time-monitoring network continued. The network will consist of three radio astronomy observatories, equipped with the most advanced instrumentation for very-long-baseline interferometry (VLBI) and a data-reduction and analysis center. Two stations are now operational—in Fort Davis, Texas, and Westford, Massachusetts—making weekly observations. Detailed comparisons with satellite laser-ranging determinations indicate that the network is achieving its design goal of 10-cm accuracy in determining pole positions. This level of accuracy was achieved with observing times of 24 hours or less. Other techniques (satellite laser, satellite doppler, and optical techniques) require days to weeks of observing to achieve comparable accuracy.

Development of Global Positioning System geodetic

receivers—in the coordinated approach agreed on by NASA, the U.S. Geological Survey, and the Defense Mapping Agency—continued toward a goal of deploying prototypes by the end of 1983. And NASA and NOAA's National Geodetic Survey established the Crustal Dynamics Project to apply space technology to understanding earth dynamics. The project supports the national program in earthquake hazard reduction, as well as national and international research in global geodynamics.

Altimetry data from the *Geos 3* Geodynamics Experimental Ocean Satellite were used to determine the mesoscale variability of the sea surface height in the western North Atlantic Ocean in and around the Gulf Stream meander region. The results agreed quantitatively with results obtained by conventional ocean-going research ships—demonstrating the potential of satellite data to supplement ship observations. *Seasat* and *Geos 3* radar-altimeter determinations of tidal constituents and mean sea surface height in the Atlantic also showed reasonably good agreement with each other, as did comparison of the tidal data with deep-sea tide-gauge measurements.

The National Bureau of Standards (NBS) began studies to determine accurately the orbits of DoD's NAVSTAR Global Positioning System (GPS) satellites after all 18 satellites are operating. With determination of the horizontal coordinates of GPS satellites to within about 20 cm, GPS signals could be used to measure crustal movements in tectonic areas and to determine orbits accurately for other satellites.

Satellite Time Service

NBS is part of a NASA-led team to provide worldwide time and frequency transfer at very precise accuracies, by integrating newest technology into the Space Shuttle time and frequency transfer system. The system will include a space-borne hydrogen-maser clock and both a laser-ranging and a microwave doppler-cancellation system at appropriate timing centers. NBS constructed a prototype GPS receiver specifically designed for international time and frequency transfer and conducted preliminary experiments with the U.S. Naval Observatory, where a similar receiver is placed. Simultaneous viewing of the same satellite yielded measurements of time and frequency differences with accuracies better than 10 nanoseconds.

Jet Propulsion Laboratory and NBS are working to keep frequency standards at the Deep Space Network (DSN) sites in Australia, California, and Spain within very precise limits of each other, for tracking deep space probes. The method now used is difficult and costly. NBS has demonstrated that simultaneous viewing using GPS satellites may greatly increase DSN synchronization accuracy at no greater cost.

The National Telecommunications and Information Administration's Institute for Telecommunication Sciences continued technical studies in preparation for the International Telecommunications Union's 1983 Regional Administrative Radio Conference on broadcasting-satellite service. Studies were to assist in determining orbit-spectrum capacity and how it might be shared with other Western Hemisphere countries. To assist in forming a U.S. position on direct-broadcast satellites (DBS) before the conference, NTIA reviewed applications filed with the Federal Communications Commission for construction of experimental DBS systems for home delivery of subscription television.

The first satellite in the International Telecommunications Satellite Organization's Intelsat V series was launched in late 1980 and entered service over the Atlantic Ocean in 1981. Two more Intelsat Vs followed in 1981. Each can transmit 12 000 voice conversations and 2 television channels. Newly installed ground stations in Saipan and American Samoa are bringing the advantages of the global system to those isolated islands. A new station also is being constructed in Palau. The recently activated International Maritime Satellite Organization was expected to begin service early in 1982 using U.S. Marisat satellites and European and INTELSAT satellites.

Space Support Activities

Measurement and Calibration Services

Spectrometer Calibration. Operating the large spectrometer-calibration chamber at its Synchrotron Ultraviolet Radiation Facility, the National Bureau of Standards calibrated a rocket payload from the California Institute of Technology, several instrument packages from Goddard Space Flight Center, and a Space Shuttle experiment from Naval Research Laboratories. The last will be flown on the spring 1982 Shuttle mission as a solar ultraviolet spectral irradiance monitor (SUSIM). An unusual feature is an in-flight recalibration capability; an NBS-calibrated deuterium lamp will fly as part of the SUSIM instrument package.

Ozone Measurements. NBS is overseeing NASA contractor plans for calibrating and operating a solar back-scatter, ultraviolet-radiation instrument to be flown on a NOAA polar-orbiting satellite. The device will measure the density and thickness of the earth's ozone layer on a global scale and detect any significant time and spatial variations of the layer. Using a new procedure for measuring ultraviolet absorption, NBS also designed a new photometer for calibrating ozone-monitoring instruments. An instrument was being

constructed to improve stability, sensitivity, and accuracy in the measurements. After performance is validated, it will supplement the NBS primary, three-meter-long photometer and will serve a calibration network for laboratories concerned with accurate ozone measurements.

Aluminum Alloys. NBS continued measuring the effect of changes in heat treatment on the microstructures and mechanical properties of aluminum alloys used in the Space Shuttle. It also measured deformation and fracture properties of two candidate materials for the scintillator in the planned Gamma Ray Observatory, *GRO*. Avoidance of creep is important for scintillator stability, and internal cracking would scatter light excessively within the scintillator.

Instrument Fabrication. NBS fabricated precision parts of the planetary mass spectrometer system for NASA's *Galileo* project. Fabrication required machining complex shapes to close tolerances and quality finishes in materials such as titanium, stainless steel, and ceramics.

Spectrometer Design. NBS advised NASA contractors on design, instrument calibration, and computer software for the high-resolution spectrograph experiment scheduled to fly on the *Space Telescope* in 1985. The bureau advised on choice of detectors and gratings, plans for preflight and in-orbit photometric calibrations, and software for command, operation, and analysis of data.

Robotics. A NASA-supported research associate worked in the NBS automation program in development of high-level languages, standards, and interfaces for sensory feedback control of robots. NASA's interest is in remote manipulators in space. From its work in robotics in machine-tool-based manufacturing, NBS was preparing a report for NASA on the state of the art in robotics and a five-year projection.

Electromagnetic Radiation Detectors. NBS was characterizing the response and principal mechanisms of operation of small-area superconducting tunnel junctions, electronic devices which, used as heterodyne receivers, are sensitive detectors of electromagnetic radiation. The thin-film devices of low-transition temperature superconductors are fabricated in an NBS facility, cooled below the transition temperature with dilution refrigerators, and tested at microwave frequencies.

Solar Activity

Solar Flares. NBS continued to work with the *Solar Maximum Mission* team on analysis of data from solar flares. The data were taken with flat and curved crystal spectrometers whose radiometric and diffraction properties were measured at NBS. Crystal calibration techniques developed in this work were made available to the x-ray astronomy and plasma physics communities.

Solar Convection. In a study of solar convection and the associated transport of mechanical energy, observations of doppler velocity with the diode-array instrument at Sacramento Peak Observatory led to detection of an intermediate-scale, steady, filamentary-like motion in the solar photosphere and chromosphere, called mesogranulation. The amplitudes, lifetimes, and horizontal scales of these mesogranular flows suggest that they may be the result of convective overshooting into the stable atmosphere. In addition, the ultraviolet spectrometer and polarimeter experiment on the *Solar Maximum Mission* satellite observed steady flows in the solar transition region.

Warnings and Forecasts

The NOAA- and USAF-operated Space Environment Services Center is the national and world warning agency for disturbances on the sun, in interplanetary space, in the upper atmosphere, and in the earth's magnetic field. A major portion of the real-time data comes from space environment monitors on NOAA's polar-orbiting and geostationary environmental satellites. In 1981, a significant improvement in short-term warning capability used new data from NASA's third International Sun-Earth Explorer satellite. The technique permits an accurate 25- to 50-minute advance warning of the beginning of geomagnetic storms. Warnings of radiation hazards from solar activity for the Space Shuttle began with its first flight in April 1981.

NOAA polar-orbiting satellites measure the total energy deposited by ionized particles precipitating downward into the earth's atmosphere in the auroral regions. Processing routines were completed sufficiently during 1981 to permit the first extensive access to the data and to make data available for real-time use in the center. A new computer system being procured will assemble, store, display, and distribute these space environment data.

Space and Atmospheric Research

Space and Atmospheric Physics

Magnetospheric Physics. NOAA's Space Environmental Laboratory developed sophisticated techniques for displaying data from experiments aboard the International Sun-Earth Explorer (ISEE) satellites. The techniques have been applied to the complete *ISEE 1* data set, and processing of *ISEE 2* data was under way. Analysis of observed characteristics of energetic particles in the geomagnetic tail permitted laboratory scientists to model a physically self-consistent mechanism for acceleration of charged particles in the geomagnetic tail and their deposition in the earth's auroral regions. This mechanism represents

a significant source for energization of magnetospheric particles.

Planetary Atmospheres. NBS continued its long-term effort to determine the far-infrared spectra of significant gaseous constituents of the outer planets. New measurements of hydrogen, hydrogen-helium mixtures, and ammonia at various pressures and temperatures were being used to formulate analytical representations for the study of planetary atmospheres.

Laboratory investigations continued into rate constants, mechanisms, and photochemistry of chemical species prevalent in the atmospheres of the planets and their satellites. Study results were used in part to predict the presence of new chemical species, which have been subsequently observed. Experimentally, NBS completed the measurement of rate constants of the primary photofragment of acetylene with hydrocarbons.

NBS made laboratory measurements of the absorption cross-sections, as they vary with temperature, of molecular species known to be present in the atmospheres of Venus, Jupiter, and Saturn. In the most recent measurements—made of sulfur dioxide—the absorption spectrum from 200 to 240 nanometers was recorded in great detail at 300 and 210 kelvins. Reduction of these data will provide improved cross-section values for more accurate analyses of planetary atmospheres.

Stellar Atmospheres. NBS compiled critical data on atomic energy levels for predicting and interpreting spectra of astrophysical sources, in the far-ultraviolet-wavelength region accessible only with instruments in space. The data are needed for research on the atmosphere of the sun and other stars. In 1981, NBS completed compilations for all 26 spectra of the astrophysically important element iron (neutral-atom and all ion stages) and for the element silicon in six ionization stages. The data permit wavelength predictions of spectral lines in solar flares, hot stars, and other astronomical plasmas and are needed for calculations and diagnostics of these plasmas.

During 1981, the International Ultraviolet Explorer (*IUE*) and *Einstein* x-ray observatory satellites helped to determine which types of stars have hot outer atmospheres similar to the sun and which show no evidence for either hot coronas or hot winds. The two types can be distinguished given the threshold sensitivities of the two spacecraft. NBS also observed flares in the ultraviolet and x-ray spectra from certain collapsed and twin stars. These data are consistent with cooling by radiation. Also, flares in the close binary systems may result from magnetic field reconnection as large magnetic loops of both stars interact.

Earth's Atmosphere. NBS laboratory measurements support NASA's upper atmospheric programs making measurements from the ground, aircraft and balloons, or spacecraft. High-resolution infrared spectra pro-

vide reliable parameters for measuring the distribution of molecular species in the upper atmosphere. The measurements contribute to understanding the long-term effects human activities may have on the earth's weather and on the protective ozone layer. During 1981, NBS made accurate measurements of the spectrum of chlorine monoxide, important to the chemistry of ozone and a product of the breakdown of halocarbons (freons) in the atmosphere. The measurements were needed for designing upper-atmospheric measurement devices; they also showed that some earlier atmospheric measurements were in error. The Air Force Geophysical Laboratory was incorporating similar measurements of several other pollutant molecules into a file of spectroscopic parameters for atmospheric studies.

Atmospheric Chemistry

Halocarbon Analysis. NBS was developing halocarbon (Freon-11) standards of concentration at the part-per-trillion (ppt) level. Since the halocarbon evaporates at room temperature, NBS developed a microgravimetric-dilution technique for producing accurate gas mixtures containing vapors of such volatile liquids. This technique is accurate to about 0.1 percent and, to achieve ppt levels, a halocarbon-air mixture is again diluted. Spectroscopic techniques using the new correct value of the absorption-band intensity of the halocarbon, which has first been measured, will provide independent verification.

Ozone Cross-Section Measurement. Determination of the dependence on temperature of the ozone ultraviolet-absorption cross-section is of particular importance to accurate stratospheric measurements and modeling. NBS measured the complete spectrum between 240 and 340 nanometers at 298 and 243 kelvins, making measurements in steps of 0.05 nanometers

with a spectral resolution of approximately 0.02 nanometers.

Aeronautical Programs

Aeronautical Charting

The National Ocean Survey produces air navigation charts to meet civilian and certain military requirements. The responsibility includes the timely collection and compilation of flight data to keep pace with the increasing demand created by advanced technology, new electronic aids to navigation, and changes in air traffic control regulations. Substantial progress was made during 1981 in evaluating Landsat images for delineating cultural and hydrographic features to update visual aeronautical charts.

Radar Techniques

NOAA's National Severe Storms Laboratory in Norman, Oklahoma, in 1981 was combining observations made using a dual-doppler weather radar system, 444-m meteorologically instrumented TV tower, surface observation network, and instrumented aircraft to expand doppler radar's potential. The detection of aviation weather hazards such as gust fronts and turbulence is possible by doppler radar. A joint program with the multiagency Next Generation Radar Joint System Program Office investigated techniques for acquiring, processing, and displaying the pertinent data. These comprehensive studies are to improve guidance to aircraft near severe weather and for public warnings. A cooperative study with the Federal Aviation Administration in the validation of the first-generation, airborne, doppler weather radars is included in the program.

Department of Energy

The U.S. Department of Energy supports civilian and military use of space through development of a range of nuclear-power systems. Nuclear power provided the electrical energy for NASA Pioneer, Viking, and Voyager missions as well as earlier earth-orbital and lunar missions. In 1981, DOE was developing radioisotope thermoelectric generators (RTGs) for the NASA *Galileo* mission and International Solar Polar Mission.

The unique characteristics of nuclear-powered electric generators—compact size, light weight, and long life—make possible operation of the sensing, analytical, and communication systems of spacecraft, satellites, and other remotely located devices for long periods without external sources of energy. Nuclear research and development in the DOE-sponsored space and terrestrial applications program delivers environmentally acceptable, operationally safe, and technically qualified energy systems to federal agencies for earth-orbital and interplanetary space missions, as well as for terrestrial applications.

Space Applications of Nuclear Power

The recent spectacular flights past Jupiter and Saturn by NASA's Voyager and Pioneer spacecraft also marked additional milestones in the continuing use of nuclear electric power in outer space. Since 1961, the United States has launched 22 NASA and military spacecraft whose power requirements were supplied, all or in part, by nuclear sources. Twenty-one were powered by RTGs and one by a nuclear reactor. Electric power output per individual nuclear source ranged from 2.7 watts for SNAP-3A to 500 for SNAP-10A. Their history has demonstrated that they can be safely and reliably built and launched to meet a variety of mission objectives.

Radioisotope Thermoelectric Generators

Development continued on an advanced silicon-germanium generator for NASA's *Galileo* mission, which is to send an orbiter spacecraft with atmospheric probe to Jupiter, and for the International Solar Polar Mission to collect scientific data on the sun and solar wind from high heliographic latitudes. This general-purpose heat-source radioisotope thermoelec-

tric generator (GPHS-RTG) is designed to provide a minimum of 285 watts of electrical power under initial space operational conditions with a fuel loading of 4410 thermal watts. It has a mass of 55.5 kilograms.

During 1981, enough GPHS modules were manufactured and tested to fuel and test the qualification unit in 1982. Production included fuel, iridium, and graphite components. Key components of the RTG Assembly and Testing Facility were completed, providing a secure facility for testing fueled generators. Multihundred-watt heat-source production and component fabrication of the *Galileo* radioisotope heater units were also completed.

The Savannah River Plant supplied the encapsulated isotope hardware for the program. The Mound Facility will support assembly of the isotope-fueled modules into a heat source, loading of the heat source into the thermoelectric converter, and testing of the fueled power unit to qualification or flight acceptance levels. Fueling and testing of both the qualification converter and the first flight converter were planned for fiscal 1983.

Advances in Supporting Technology

DOE prepared a new RTG design taking advantage of new materials, fabrication techniques, and design concepts, to analyze the potential for a more advanced, much lighter weight RTG for future space missions. The design of this modular isotopic thermoelectric generator (MITG) permits changing the power level. Except for its end sections, the generator consists of a number of identical slices of standard design, each producing approximately 24 watts at 28 volts. The basic design is adaptable to many uses, since the output power can be scaled in 24-watt steps by varying the number of standard generator slices, usually without other design changes. In addition, any intermediate power level can be provided by minor modification of the radiator fin dimensions. In the earlier multihundred-watt generator, changing the power level required a major redesign and requalification of the heat source. And even in the GPHS generator, which uses the same modular heat source as the MITG, changing the power level would usually require major changes in the thermoelectric couples and circuit.

The MITG also promises a substantially higher specific power than present-generation RTGs. The increase is achieved without any reduction in safety and probably with increased reliability, because of the ability to check the performance of individual thermoelectric modules in the assembled converter and—if necessary—to replace deficient ones. In the long run, the MITG should be more economical, because of the modularity, scalability, and greater flexibility in matching the payload's voltage requirements.

During 1981, DOE continued development of advanced thermoelectric materials and power modules. It continued space power and engineering analyses, conceptual design, quality-assurance inspection review, and reliability assessment.

Space Reactor Technology

Nuclear reactors are another power source for generating electricity on spacecraft. Like the RTGs, reactor power plants are basically heat engines; they convert the heat from the fissioning of uranium-238 into electricity through either static (e.g., thermoelectric-element) or dynamic (e.g., rotary-shaft) subsystems. The reactor power system has growth potential because of the greater energy release available in the fission process (almost 200 million electron volts per fission of uranium-238 versus about 5.5 MeV per alpha emission from plutonium-238). From a weight standpoint, a space reactor becomes competitive with other power sources at levels above 25 electrical kilowatts, but the choice of nuclear power source depends on the needs of the spacecraft mission.

During 1981, the Los Alamos National Laboratory completed the engineering design layout of a space reactor and its shield assembly, analyzed water immersion effects on reactor criticality, and tested performance of reactor-core heat pipes and compatibility of the material with the working fluids. An interagency agreement was initiated with NASA for component technology development of an SP-100 space power nuclear reactor targeted for potential use in the 1990s.

Nuclear Waste Disposal

Concepts were being evaluated in 1981 for using the Space Shuttle to place nuclear wastes in space as a

method for permanent disposal. The method would supplement but not replace terrestrial methods. The principal terrestrial method being developed was use of repositories in deep geologic formations.

Remote Sensing of the Earth

Satellite sensing and analysis continued to prove useful in geologic and environmental research applications. This research was conducted for DOE under contract with the national or dedicated laboratories and with universities. The department also continued to be represented on the interagency Program Board on Civil Operational Land Remote Sensing from Space.

Nuclear Test Detection

DOE's predecessor, the Atomic Energy Commission, was responsible for developing nuclear-test-detection instrumentation for the DoD-managed Vela satellites. Six pairs of Vela were launched from 1963 to 1970 to monitor nuclear tests in the atmosphere and space after the 1963 Limited Test Ban Treaty forbade testing in these regimes. Although the last Vela satellites are now severely degraded, some continued to function during 1981.

This surveillance mission is now incorporated into other multimission DoD satellite programs. DOE is responsible for sensor design, fabrication, test, calibration, and some launch and operational support. DoD manages spacecraft procurement, sensor integration, launch schedules and costs, and satellite operations.

DOE research and development improves existing capabilities and supports new detection requirements. DOE research also seeks a better understanding of the space environment in which satellites operate. Theoretical modeling, sensor development, and flight testing on NASA and DoD space systems provide data to designers and astrophysicists, leading to improved surveillance instrumentation and enhanced understanding of the radiation environment of space.

Department of the Interior

The U.S. Department of the Interior is responsible for the management, conservation, and development of the natural resources on the nation's public lands and is specifically designated caretaker for more than 2 million square kilometers of these lands. In the inventory, management, and monitoring of vast and often inaccessible areas, the department frequently relies on data acquired by airborne sensing systems. In the past 10 years, data acquired by sensing systems carried aboard satellites, particularly the Landsat series, have also been used experimentally for mineral and energy resource exploration as well as for monitoring the environment. Effective management has been facilitated by conducting research in digital data analysis and by the development of new applications of Landsat and other remotely sensed data and related technologies.

Bureaus and agencies of the Department of the Interior participating in remote-sensing studies during 1981 included the Bureau of Land Management (BLM), Bureau of Reclamation, Office of Surface Mining Reclamation and Enforcement, U.S. Fish and Wildlife Service, and U.S. Geological Survey's Earth Resources Observation Systems (EROS) Office, Geologic Division, National Mapping Division, and Water Resources Division. Also working with Interior were the U.S. Army Corps of Engineers and the Department of Labor's Mine Safety and Health Administration.

Earth Resources Observation Systems Program

The mission of the EROS Office is to develop, demonstrate, and encourage the practical use of remotely sensed data acquired by aircraft and spacecraft. EROS develops basic criteria for the remote sensing of features of the earth and coordinates data requirements, system configurations, and product formats with other agencies. It conducts, sponsors, and coordinates research applying remotely sensed data to mapping, geography, and mineral, land, and water resources. It also sells and distributes data and provides specialized training and assistance in their use.

The EROS Data Center near Sioux Falls, South Dakota, is the primary archive and distribution center

for remotely sensed data. It also supports training, research, and engineering development activities. In 1981, 240 scientists and technicians from Interior, other federal and state agencies, and foreign countries received training in remote sensing at the center. Sales of remotely sensed data totaled more than \$4.3 million (\$2.5 million in Landsat-related sales and \$1.8 million in other sales, primarily aerial photographs).

Applications and Research

The department, particularly the U.S. Geological Survey, has been evaluating several remote-sensing systems for potential multidisciplinary applications. The information derived is also useful for designing and developing future aircraft and satellite remote-sensing system parameters.

Mineral Resource Surveys. With NASA funding, EROS made a preliminary analysis of global magnetic anomalies. The NASA *Magsat* satellite, launched in 1979, has provided the first worldwide set of geomagnetic data of high, uniform standard. Together with information on known mineral deposits, these data may improve understanding of resource origin, distribution, and regional potential.

In cooperation with NASA's Jet Propulsion Laboratory and other NASA offices, the Geologic Division prepared for the Space Shuttle test flight of the Shuttle multispectral infrared radiometer (SMIRR). The new device operates on 10 channels in the spectral region of 0.6 to 2.5 micrometers and may detect altered ground indicative of mineral deposits. In November, the second flight of Shuttle orbiter *Columbia* recorded 186 minutes of SMIRR data over desert regions of Mexico, Spain, Italy, Greece, Turkey, Morocco, Egypt, and Saudi Arabia. Unfortunately, test areas in the United States and Australia were covered by clouds. Data will be studied to evaluate the spectral bands chosen for geologic mapping and to aid in designing future scanners.

Land and Land-Cover Surveys. EROS and the National Mapping Division continued to fund studies jointly with NASA's Wallops Flight Center to evaluate land applications of the *Seasat* satellite's radar altimeter. The altimeter has proved of value in accurately determining elevations in areas that are relatively flat. Tests over the Bonneville Salt Flats in

the Great Salt Lake Desert provided new elevation information in a detail not usual in standard mapping programs. Use in areas of subsidence due to withdrawal of ground water or petroleum—such as the San Joaquin Valley; Eloy area, Arizona; and Houston—was tested to an accuracy of 20 centimeters. The altimeter was also tested over tropical regions such as the Florida Everglades, where detailed wave-form studies demonstrated that the radar reflections from the tops of trees and swamp grass can be accurately distinguished.

Seasat L-band synthetic-aperture radar imagery discriminated flooded wetland forest from other surrounding forest. Analysis was most effective in the nearly level areas of the Atlantic and Gulf coastal plains. The Geologic Division tested *Seasat* digital data for geologic mapping in heavily vegetated areas. L-band radar imagery and the radar altimeter also mapped snow and ice features and surface elevations of major ice sheets. These studies defined not only the applications of the abundant data acquired in the *Seasat* experiment, but also the parameters for a new radar altimeter that could be flown on a future stereomapping satellite.

Congress specified in the Department of the Interior's fiscal 1980 appropriations act that the Geological Survey should "begin the use of side-looking airborne radar imagery for topographic and geological mapping and geologic resource surveys in promising areas, particularly Alaska." Radar imagery acquired and analyzed in response indicated tentatively that radar images can supplement other data sources or substitute for aerial photographs in persistently cloud-covered areas in some geologic, hydrologic, and cartographic applications. Radar data, however, are more expensive to acquire than Landsat images and aerial photographs. Results of this research and recommendations were presented to the Congress at the end of 1981.

Energy Resource Surveys. The Geologic Division completed an investigation for NASA on geologic applications of thermal-infrared satellite data received from the *HCMM* Heat Capacity Mapping Mission launched in 1978. In test areas in Arizona and Wyoming, even at 500-meter resolution, thermal-inertia images permitted discrimination of some rock types, delineation of structural features, and subtle anomalies possibly related to deeply buried oil and gas deposits. New computer models for handling thermal-infrared data on a regional scale were also developed.

Pollution and Resource Surveys. The Geological Survey and NASA cosponsored a workshop on applications of luminescence techniques to earth resources studies. Attendees from the federal government, industry, and universities reviewed results previously achieved with the Fraunhofer line discriminator (FLD), an optical-mechanical device for measuring, from aircraft, extremely low levels of luminescence of

materials on the earth's surface. Luminescent material detected included marine oil seeps, sedimentary phosphate- and uranium-bearing rocks, stressed vegetation, and industrial pollutants. The group recommended that an improved imaging FLD be built to continue aircraft work and for experimental use aboard the Space Shuttle.

Data Handling

EROS and the National Mapping Division made significant progress during 1981 in computer-aided information handling and data processing of geographic and remotely sensed data. EROS developed techniques for integrating and merging disparate digital data sets to produce spatial data bases on natural resources for analysis, planning, and management. For example, a cooperative EROS and Bureau of Land Management project was evaluating the feasibility of merging Landsat multispectral-scanner data and soils data to expedite the bureau's soil-vegetation-inventory method of mapping ecologically significant zones.

The National Mapping Division sponsored research at the University of Arizona that demonstrated the data rate of multispectral digital image data might be decreased without a corresponding loss of information, by recording one dominant band at high resolution and the others at lower resolution. This concept is important to the design of an operational earth-sensing system.

Remote Image Processing

EROS undertook a project to define the specifications of a remote image processing station (RIPS) designed to extend the use of Landsat and other remotely sensed data. Electronic enhancement to select and amplify specific data from Landsat images is now done in sophisticated, expensive computer laboratories. The RIPS project is investigating the use of small, inexpensive computers in field offices to perform similar functions independently for some tasks and through communication with a large "host" computer for other tasks. In 1981, a workshop discussed the numerous processing functions and interface capabilities of RIPS that will enable it to analyze geographically referenced data from several sources, such as Landsat, meteorological, topographic, and cartographic data.

Monitoring the Environment

Aircraft and satellite sensor data are routinely used by the bureaus and agencies of the Department of the Interior and other federal agencies to monitor all aspects of the environment, from the atmosphere to the earth's surface.

The National Mapping Division used Landsat digital data to map land cover in the National Petroleum Reserve area in Alaska. Efforts in 1981 included the Prudhoe Bay Region and, in cooperation with the U.S. Fish and Wildlife Service, the Arctic National Wildlife Refuge. Preliminary products of the digital analyses were provided to cooperating agencies. The Bureau of Land Management used the data with digital terrain data to assess potential impacts of lease sales.

High-altitude color-infrared photographs were studied to determine whether cropland could be differentiated from pasture in three Louisiana parishes. Field verification revealed an interpretive accuracy level of 74 percent (Geological Survey's accuracy standard is 85 percent), suggesting that separation of cropland from pasture on such imagery should not be a standard practice.

In 1981, BLM, EROS, and NASA completed a three-year project developing techniques for using Landsat digital data to identify vegetation in three areas typical of BLM's management responsibility—northern spruce-tundras in Alaska, ephemeral desert ranges in Arizona, and intermontane sagebrush-grassland in Idaho. Satellite technology saved more than \$20 per square kilometer over costs of labor-intensive ground surveys. To capitalize on this technology, BLM established and equipped its own laboratory at the Denver Service Center to process Landsat digital data.

Land-cover classification techniques were used to inventory vegetation on 48 000 sq km in Arizona, New Mexico, Idaho, and Alaska. The computerized land-cover base is merged with additional digitized data such as that on roads, land ownership, elevation, slope, soils, and water sources to provide a broad base of information for planning and assessing land use.

Forest Fuels Mapping and Fire Control

For various areas of responsibility in Alaska, BLM prepared fuel-load maps from Landsat images for use with automatic lightning detectors for rapid assessment of potential fire risk. Similar fuel-load maps were prepared for 4000 sq km in the Vail, Oregon, district.

Water Resource Analysis

Data acquired by an airborne multispectral scanner were being used by the Bureau of Reclamation to measure the trophic state of lakes and reservoirs in the western United States. Landsat multispectral-scanner data were also being tested for this purpose. Surface measurements were taken from the water bodies at the time of satellite overpass to develop correlations for these studies. The ultimate purpose is to reduce the

need for extensive and costly ground surveys to measure water quality.

Using digital Landsat, terrain, and other data, the Water Resources Division mapped numerous terrain classes in drainage basins in Tennessee, New Mexico, and Nevada. Land cover (related to streamflow) in the basin was mapped to evaluate runoff and predict future water conditions, such as low, mean, and peak streamflow. The Bureau of Reclamation was using thermal-infrared imagery acquired by aircraft to locate thermal springs near the proposed site for Roosevelt Dam on the Salt River in Arizona. The integrity and safety of major dams and water conveyance structures in the western United States were studied by interpreting geostructural features with the aid of computer-enhanced satellite imagery.

Irrigation Analysis

In cooperation with the U.S. Army Corps of Engineers, Portland District, EROS developed and tested techniques using Landsat and geographic data to evaluate irrigation agriculture in the 6500-sq-km Umatilla River basin in Oregon. Landsat data were manually interpreted to map the growth of irrigation from 1973 to 1979 and then digitally analyzed to identify crops under irrigation in 1979. The crop data were used with historical agricultural data and digitized topographic and hydrographic data to estimate water and power use in 1979. A composite map of land suitability for irrigation development was produced from Landsat-derived land-cover information and data on land ownership, soil irrigability, slope gradient, and potential energy cost.

The National Mapping and Water Resource Divisions continued investigations in the High Plains. Methods for mapping irrigated cropland by digital analysis of Landsat data were evaluated, and maps were used to estimate ground-water withdrawal. A total of 59 Landsat scenes were prepared for a digital model of the Ogallala aquifer, the main ground-water-bearing formation underlying the High Plains. The data will be used to calculate the total amount of water pumped from the aquifer for irrigation.

Weather Monitoring

The Bureau of Reclamation uses aircraft for data collection, cloud seeding, and observation in Skywater, a project designed to accelerate development of reliable and efficient techniques for increasing rainfall from summer showers and snowfall from winter orographic storms. The GOES Geostationary Operational Environmental Satellites operated by the National Oceanic and Atmospheric Administration collect cloud imagery in near real-time. Meteorological satellite data help forecast and control experimental activities on all Project Skywater field projects.

The bureau was also using GOES digital data to observe summertime convective cloud activity for the High Plains Cooperative Program (HIPLEX) in Montana and Texas and to observe wintertime extratropical storm systems for the Sierra Cooperative Pilot Project (SCPP) in California and the Colorado River Augmentation Demonstration Program (CRADP) in a five-state region of the Rocky Mountains. The HIPLEX observations seek to determine the frequency, distribution, and size of clouds that produce precipitation. SCPP observations are to determine the extent to which cloudtop temperatures can be monitored from geosynchronous altitudes. In CRADP, analyses of cloudtop temperatures and mesoscale features will produce a climatology of wintertime storm conditions in six subbasins in the Colorado River basin.

In 1979 the bureau contracted for development of a solar-powered portable, remote-observation-of-environment (PROBE) station. By the end of 1981, 150 PROBE stations had been constructed and some 125 were operating. Each station measures and reports wind speed and direction, temperatures, relative humidity, barometric pressure, precipitation, and the status of the unit's power-package battery. Measurements are transmitted hourly by radio to a satellite. The system can record up to 240 stations per hour and disseminates the data to project sites, providing scientists near real-time information.

Mine Development and Safety Monitoring

Mine-related features in low-altitude aerial photographs assist in inspection of permit compliance and enforcement of regulations in the Appalachian states. Aerial photography and imagery also help evaluate mining impact, review mine plans, and analyze problems in active or abandoned mines. The Office of Surface Mining is developing the capability to monitor mining with high-altitude aircraft and Landsat data. BLM has successfully monitored albedo change on temporal Landsat images to identify mine trespass in Florida and Alabama.

The Mine Safety and Health Administration, Department of Labor, used Landsat imagery and high-altitude photography obtained through the Geological Survey to improve safety for miners. The data were interpreted to delineate geologic weakness that might reduce mine stability. Return-beam-vidicon (RBV) imagery proved especially useful in detecting geologic discontinuities in the earth's crust. Finding such areas in advance of actual mining reduces the potential for rock falls and cave-ins, a leading category of mine accidents.

Geology

Structure and Alteration

Using improved computer techniques in Landsat studies, the Geologic Division continued to define new relationships between structural features (many not previously mapped) and alteration related to mineralizing processes. Other Landsat studies clarified structural settings of prospective radioactive-waste isolation areas of the Paradox basin, Utah, and the Cascade Range zone of active volcanism.

Lineament Analysis

Rock fractures, faults, and joints—frequently indicative of ground water, minerals, and petroleum—are evidenced by lineaments on Landsat images. EROS developed a procedure to produce lineament maps based on objective digital processing, for use by geologists.

Cartography

Image Maps

After more than 10 years of study and experimentation, the National Mapping Division succeeded in the conceptual definition of a candidate operational earth-sensing satellite system that combines stereo-coverage, improved resolution and geometry, and multispectral capability with simple, cost-effective operation. Multicolor image maps at scales as large as 1:50 000 with 20-meter topographic contour intervals are envisioned as one of the products of the system. A study by the industrial team of Itek and TRW indicated that the *Mapsat* satellite concept is technically feasible and could make an operational system economical and practical.

A 1:100 000-scale map of Cape Cod and vicinity was prepared by making a mosaic of *Landsat 3* return-beam-vidicon images. It will provide an image base for a geologic map and an intermediate-scale planimetric map. A 1:250 000-scale map of the Ikpikpuk River quadrangle in Alaska was also compiled from RBV images.

Index Maps

A set of 26 map sheets titled the "Worldwide Reference System" (WRS) was designed for cataloging Landsat images. The WRS consists of a global network of 251 paths and 119 rows whose intersections correspond to geographic locations over which Landsat "nominal scene" centers are located. A single RBV image from *Landsat 1* or *2*, a set of four RBV subscenes from *Landsat 3*, or a single multispectral scanner image from all three Landsats covers a

nominal scene. Several index sheets were printed and the rest scheduled for late January 1982. Some 2500 Landsat nominal scene centers have been identified and their quality indicated for an "Index Map to Optimum Landsat Images of Antarctica." The 1:5 000 000-scale base map will also include a tabular presentation of image identification and related information.

Landsat Receiving-Station Map

A graphic outline was prepared of the reception-radius areas over which *Landsat 1*, *2*, and *3* and the planned *Landsat-D* and *-D'* data can be received in real-time by ground stations throughout the world. Data acquired over areas outside this coverage must be tape-recorded from *Landsat 1*, *2*, and *3*, or be received through the planned Tracking Data and Relay Satellite System (TDRSS) for *Landsat-D* and *-D'*.

International Activities

International activities of the Department of the Interior are conducted largely on behalf of the U.S. Department of State. Technical assistance programs to aid developing countries in using remote-sensing technology are conducted under the Agency for International Development (AID) in accordance with the U.S. Foreign Assistance Act. Bilateral scientific cooperation is sponsored by the participating agencies and governments. Multilateral activities are carried out under the United Nations.

During 1981, U.S. Geological Survey scientists held two, month-long remote-sensing workshops for a total

of 34 scientists from 21 countries at the EROS Data Center. Three advanced remote-sensing courses were held at the Geological Survey's Center for Astrogeologic Studies in Flagstaff, Arizona, for 12 scientists from 9 countries. The Organization of American States sponsored a course on "Applications of Remote Sensing in Hydrology," conducted by Geological Survey scientists for the Comisión Nacional de Investigaciones Espaciales in Argentina.

In 1981, technical expertise on interpretation of remotely sensed data and preparation of Landsat image mosaics was provided in cooperative projects with Greece, Mexico, Morocco, Pakistan, Saudi Arabia, and Thailand. The International Atomic Energy Agency and the Organization for Economic Cooperation and Development sponsored Survey-conducted Landsat studies on the relationship of structural features and alteration to uranium mineralization for test areas in France, England, Canada, Australia, Sweden, Norway, Greenland, Turkey, and the United States. In a satellite glaciology project, the Survey undertook—with 55 scientists from 30 U.S., foreign, and international organizations—to prepare a satellite-image atlas of glaciers of the world. Emphasis during 1981 was placed on analysis of Landsat multispectral scanner images of Antarctica. A technology transfer project sponsored by AID was conducted for Tunisia.

The Survey continued as lead agency for the International Geological Correlation Program's Project 143 on Remote Sensing and Mineral Exploration, jointly sponsored by the United Nations' Educational, Scientific, and Cultural Organization and the International Union of Geological Sciences.

Department of Agriculture

Continued development of remotely sensed data as a source of information for research and operational programs was the focus of space activities in the U.S. Department of Agriculture (USDA) during 1981.

The department entered the second year of the AgRISTARS (Agriculture and Resource Inventory Surveys through Aerospace Remote Sensing) program—a multiyear, multiagency research program designed to determine applications of aerospace technology to agriculture and renewable resources. With direct participation and assistance from NASA and the Departments of Commerce and the Interior, and with the Agency for International Development participating in an advisory role, the USDA-led program stimulated experimental use of aerospace remote sensing for agriculture.

Although the AgRISTARS program is focused on longer-term research objectives, interim milestones were reached and individual research projects within the broad program reported specific achievements. For example, the Early Warning/Crop Assessment project continued developing and testing soil-water models to assess crop stress due to lack of moisture and assisted in interpreting related data from environmental satellites. It also aided transfer of evaluation procedures and techniques to operational use.

The Domestic Crops and Land Cover project, developing procedures to identify and measure land cover (including major crops), used data from Landsat satellites to improve accuracy of data classification at local and state levels. Significant research accomplishments included improved estimates for wheat in Kansas, corn and soybeans in Iowa, and rice in Arkansas. First steps were taken toward integration of Landsat-derived data with ground-based acquisition and processing at state agricultural statistical offices.

The objective of the Soil Moisture project is to develop ways to estimate moisture content using sensors in space, as well as aircraft and ground sensors. Better information about soil moisture will improve early warning alerts of changes that affect crop production and quality and therefore estimates of crop yields. Research during 1981 sought a better understanding of the effects of environmental factors—such as soil types, terrain roughness, and vegetative

cover—on moisture determination using remote sensors.

The Renewable Resources Inventory project develops and tests new ways to collect, display, and use remotely sensed data for forest and rangeland planning and management. Landsat technology is being evaluated as a tool in resource inventories and planning. Other areas include improving the capability to monitor and measure changes in forests and rangeland and to map natural and managed habitats. Research to date indicates that use of Landsat data in conjunction with geographic information can improve resource inventories.

The Conservation/Pollution project improved accuracy in predicting runoff from a watershed, using satellite observations of snow cover. Other significant accomplishments included determining relationships between microwave data and snow depth and estimating amounts of sediment suspended at the surface of bodies of water by observing reflected solar radiation.

Automation of Landsat data for identification and measurement of crop acreage was improved in the Foreign Commodity Production Forecasting project. The NASA-led activity develops methods for using aerospace remote-sensing technology for objective, timely, and reliable forecasts of foreign crop production.

The Supporting Research project develops procedures to extract information from Landsat data to be tested in other projects. Research emphasis was on spectral analysis of crops to determine crop conditions, as well as development of techniques to delineate crop acreage and stages of growth.

Research in the Yield Model Development project develops mathematical models, or equations, incorporating data on plant growth characteristics, soils, weather, and other environmental factors, to represent the yield potential of different crops.

Specialists in the Foreign Agricultural Service extended crop-stress detection techniques and combined satellite-derived information with weather data and ground-based information to improve crop assessment capabilities. During 1981, some 100 assessment reports, covering 10 major countries or regions, were produced.

Federal Communications Commission

Demand for satellite communication services continued to grow in 1981; programs expanded to serve both international and domestic traffic increases. The 12-satellite global and domestic service of the International Telecommunications Satellite Organization (INTELSAT) was upgraded by launches of the second and third Intelsat V satellites, and proposals for the advanced Intelsat VI series were being evaluated. Eleven U.S. domestic commercial satellites were in service at the end of the year, with six additional satellites scheduled for launch in 1982. The International Maritime Satellite Organization (INMARSAT) was preparing to begin commercial maritime service early in 1982. Plans for direct broadcast satellites (DBS) were being formulated to permit direct-to-home program distribution.

Communications Satellites

INTELSAT

Satellites in service in INTELSAT's global communications system at the end of 1981 were two Intelsat IV-A satellites, one Intelsat IV, and one Intelsat V in the Atlantic Ocean region; two Intelsat IV-A satellites in the Indian Ocean region; and one Intelsat IV in the Pacific region—plus four in-orbit contingency and leased-domestic-service satellites. First transfer of traffic to a high-capacity Intelsat V began in 1981. The third Intelsat V, launched in December 1981, will go into service over the Atlantic in early 1982, while the second, launched in May 1981, will move from the Atlantic to the Indian Ocean region. The first, launched in December 1980, will remain an in-orbit spare over the Atlantic. Intelsat Vs operate in both 6–4 and 14–11 gigahertz (GHz) frequency bands, along with a cross-strap mode (up on 6 GHz and down on 11, up on 14 GHz and down on 4).

INTELSAT planned launches of up to six more Vs in the next two years, followed by six improved Intelsat V-As in 1984 and 1985, to meet international traffic demands—expected to double in the next four years—as well as providing regional and domestic services to its member nations. The last four Intelsat Vs will be able to provide maritime services and are expected to be leased by INMARSAT. INTELSAT ap-

proved introduction of time-division multiple access (TDMA)—a transmission technique that will markedly increase the capacity of its satellites. Industry proposals for Intelsat VI were being reviewed, and a contract award was scheduled for early 1982.

Maritime

Commercial maritime, mobile-satellite service also continued its expansion. At the end of 1981, service through the Marisat system (managed by Comsat General Corp.) was provided in the Atlantic, Pacific, and Indian Ocean areas to some 950 ships—almost double the number served in 1980. Beginning 1 February 1982, INMARSAT will take over and expand the Marisat services still further. The increased capabilities will be provided by a combination of existing Marisat satellites, European Space Agency Marec satellites, and Intelsat V satellites. INMARSAT estimates that 2000 ship terminals will be in use by 1985 and 5000 by 1990—or even more if low-cost, data-only terminals are introduced. Planning continued for a future global maritime distress and safety system expected to be put into operation by about 1990. It will rely heavily on satellite communications for distress alerting and for search and rescue coordination.

Domestic Commercial Communications Satellites

The commission in December 1980 authorized construction of 25 new domestic satellites and launch of 20 of these or previously built satellites. In October 1981, it authorized construction of two additional satellites. The new satellites are scheduled to replace those now nearing the end of their operational lifetimes, to provide for new entrants into the domestic market, and to expand the facilities of existing carriers. At the end of 1981, Hughes Communications, Inc., was constructing three Galaxy satellites to operate in the 4–6 GHz bands. Galaxy-A was scheduled to be launched in June 1983 and Galaxy-B in September 1983.

Southern Pacific Communications Company was constructing four Spacenet satellites to operate in the 4–6 and 12–14 GHz bands. The first two were to be launched in February and October 1984.

Comsat General Corp.'s *Comstar D-4* was launched in February 1981 and parked at 127.25° west longitude. *Comstar D-1* was relocated from 127.5° to 95° W., where it operates with *Comstar D-2* as a composite satellite. *Comstar D-3* was at 87° W.

American Telephone & Telegraph Company was constructing three Telstar satellites to operate in the 4-6 GHz bands. Telstar-A was scheduled to be launched in July 1983 and Telstar-B in May 1984, to replace Comstar satellites.

RCA American Communications, Inc., was constructing six additional Satcom satellites to operate in the 4-6 GHz bands. *RCA-Satcom 3-R* (replacement for *RCA-Satcom 3*, which was lost in space in late 1979) was launched in November 1981 and parked at 131° W. *RCA-Satcom 4* was to be launched in January 1982, *RCA-Satcom 5* in October 1982, *1-R* (replacement for *RCA-Satcom 1*) in March 1983, and *2-R* in August 1983. The sixth satellite will be an on-ground spare. *RCA-Satcom 1* was parked at 135° and *RCA-Satcom 2* at 119° W.

The Western Union Telegraph Company was constructing three additional Westar satellites to operate in the 4-6 GHz bands. *Westar 4* was to be launched in February 1982 to replace *Westar 1*, and *Westar 5* to be launched later in 1982 to replace *Westar 2*. *Westar 6* was also under construction. *Westar 1* was parked at 123°, *Westar 2* at 99°, and *Westar 3* at 91° W.

Space Communications Company (Spacecom)—a partnership of Western Union (50 percent), Fairchild Space Communications, Inc. (25 percent), and Contel Space Corp. (25 percent)—will construct and operate the TDRSS/Advanced Westar system of four in-orbit space stations and a ground spare. The first two satellites will be used exclusively for Tracking and Data Relay Satellite System (TDRSS) service in government frequency bands, the third exclusively for commercial domestic satellite services in the 4-6 and 12-14 GHz bands, and the fourth for both TDRSS and commercial services. Spacecom is also authorized to construct and operate the associated tracking, telemetry, and command ground station at White Sands, New Mexico. Western Union will lease 50 percent of Advanced Westar, and American Satellite the other 50 percent. The first Advanced Westar satellite was scheduled for launch by NASA's Space Transportation System (STS) in January 1984 and the second in May 1984.

GTE Satellite Corporation (GSAT) was building three satellites to operate in the 12-14 GHz bands. The GSAT system will be operated separately from the joint AT&T-GSAT operation. GSTAR-A was scheduled to be launched in March 1984 and GSTAR-B in September 1984.

Satellite Business Systems (SBS) was constructing two additional satellites to operate in the 12-14 GHz bands. SBS began its commercial satellite operations in March 1981 with a satellite at 100° W. A second

SBS satellite was launched in September 1981 and parked at 97° W.

At the end of 1981, nine domestic communication satellites were operating in the 4-6 GHz bands and two in the 12-14 GHz. Of the nine in the 4-6 GHz bands, three were part of RCA American Communications' Satcom system, three in Western Union Telegraph's Westar system, and three in AT&T's Comstar system. These satellites provide message toll service, television distribution, and both single channel per carrier and multiple channels per carrier for voice, data, TV, and digital data. More than 5000 ground stations were licensed for these services. Many stations use 4.5-meter antennas to receive and distribute video and audio signals. The two satellites in the 12-14 GHz bands were operated by SBS to provide a wideband, switched, private communication network to large industrial and government users on a commercial basis, using 5- or 7-meter-antenna ground stations. Voice, data, and image traffic is assembled into a digital stream and all the digital carriers use TDMA to the satellite's transponder.

The commission initiated a Notice of Inquiry and Proposed Rulemaking in November 1981 to consider the cost and benefits of reducing orbital spacings to 2° and associated orbital location-assignment policies for the next generation of domestic satellites. Reduced spacing will provide additional orbital locations to accommodate entry of new satellite systems into the market place and permit expansion of existing systems. Reduced orbital spacing for satellites operated in the 4-6 and 12-14 GHz bands may be achieved by adhering to coordinated design practices and using ground stations with antennas of improved sidelobe and cross-polarization discrimination performance. The commission's staff made a detailed technical examination of the feasibility of reduced satellite spacing. Comments were being requested from the public and the satellite industry before final orbital assignments in 1982.

Experiments and Studies

Experiments in emergency communications using Applications Technology Satellites *ATS 1* and *ATS 3* continued (see the NASA chapter), as well as collection and relay of environmental data by the Geostationary Operational Environmental Satellites (see the Department of Commerce and NASA chapters). Studies and planning for international regulations for communications satellites and for direct-broadcast satellites made progress.

Communications Studies

U.S. preparations continued toward the World Administrative Radio Conference (Space WARC), which will seek to guarantee in practice for all countries

equitable access to the geostationary satellite orbit and the frequency bands allocated to space services. The first session of this conference, scheduled for six weeks beginning in July 1985, will decide on space services and frequency bands and establish the principles, technical parameters, and criteria for the planning; establish guidelines for regulatory procedures for those services and bands where sharing is not appropriate; and consider other approaches to guarantee equitable access to the geostationary orbit.

The second session of this conference, scheduled for six weeks beginning in September 1987, will implement results of the first session.

In December 1980, the commission released a first notice of inquiry requesting public comment on commission preparation for the Space WARC. Comments on policy issues and planning approaches were received in early 1981. Additionally, the commission established the FCC Advisory Committee to bring the nongovernment sector into the decision-making process for the Space WARC. The Advisory Committee held its first meeting in September 1981. A second notice of inquiry was released in late 1981.

Direct-Broadcast Satellites (DBS)

Proposed direct-broadcast satellites would be placed in geostationary orbit to beam programs to individual homes without the intermediary of local television stations or cable systems. The home receiver—a small

antenna (parabolic “dish”) and circuitry inside the home to process the received signal—would be connected to an existing TV receiver. Service areas in the United States are expected to receive at least three channels from a single satellite, and many satellites could serve a given service area. The downlink frequency will be in the 12-GHz band and the uplink in the 17-GHz band.

In 1981, the commission issued a Notice of Proposed Policy Statement and Rulemaking proposing interim rules and frequency allocations for DBS and received comments. The proposed rules would impose only the minimum requirements necessary to ensure that DBS systems operated in conformity with the Communications Act and international agreements. Final rules for interim systems were to be adopted early in 1982. FCC tentatively accepted eight applications requesting authority to provide DBS service to the continental U.S., Alaska, Hawaii, Puerto Rico, and the Virgin Islands. Decisions on applications were expected in early 1982.

Planning with 32 Western Hemisphere administrations was under way for DBS spectrum requirements in Region 2. Studies continued on service areas, orbital locations, and channel assignments for countries in Region 2—North America, Central America, the Caribbean, and South America—in preparation for the Regional Administrative Radio Conference in Geneva in June 1983. Several notices of inquiry have brought numerous comments.

Department of Transportation

The Federal Aviation Administration (FAA), the U.S. Department of Transportation's aviation component, operates under authority of the Federal Aviation Act of 1958 (as amended), a statutory charter that has aviation safety as its principal objective. FAA regulates air commerce to promote its safety and development, fosters civil aeronautics at home and abroad, develops and operates a common system of air navigation and traffic control for civil and military aviation, fosters development of a national airport system, regulates airport safety, promotes aviation security, and ensures that civil aviation operations damage the environment as little as possible.

FAA research, development, and engineering programs fall into three principal categories: enhancing aviation safety, protecting the environment, and increasing the safety and efficiency of air navigation and traffic control. While FAA contractors conduct most of these activities, a substantial number are accomplished in concert with DOT's Transportation Systems Center, NASA, the Department of Defense, and, as opportunity affords, with agencies of friendly foreign governments. In addition, FAA's Technical Center in Atlantic City tests and evaluates systems, and FAA's Civil Aeromedical Institute in Oklahoma City engages in aeromedical research.

Aviation Safety

Recent Initiatives

During 1981, FAA

- Conducted with the Canadian government's National Aeronautics Establishment airworthiness tests basic to the certification of helicopters for operations under instrument flight rules (IFR).
- Began collecting information on engine failures in wide-bodied aircraft caused by bird strikes, to assist in establishing technical criteria for preventing such failures.
- Joined NASA and DoD in forming a national task force to determine the test facilities needed for research and development in icing, especially as related to certification.
- Participated in a NATO Advisory Group for Aerospace Research and Development (AGARD) report that assessed the state of the art on helicopter icing and recommended future R&D.
- Supported the Southwest Region effort to certify the Bell 412 helicopter, the first civil helicopter designed for flight in known icing conditions, by preparing guidelines for its certification.
- Analyzed helicopter operational experience and identified actions that might reduce pilot-caused accidents.

Fire Safety

The Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee established by FAA in mid-1978 to review its fire safety research program reported to the FAA administrator in the fall of 1980. It recommended development of an antimisting kerosene (AMK) technology as the most effective action the FAA could take in reducing postcrash jet transport fires, which occur when fuel tanks rupture and the released fuel, in the form of a fine mist of combustible vapor, spontaneously ignites.

The FAA for some 10 years had been working with NASA and the British Royal Aircraft Establishment (RAE) in developing FM-9, a kerosene jet-fuel additive of British origin. In November 1980, RAE and FAA conferees agreed that the additive was technically feasible and that, if it could be produced at reasonable cost and incorporated into existing jet fuel systems, it would significantly reduce fire hazards. In February 1981, a conference of NASA, RAE, industry, and public representatives concluded that adding FM-9, or a similar substance, was the best way to inhibit formation of the postcrash fireball. Conferees also concluded that much work remained to be done in ensuring production of the additive at reasonable cost; determining the concentration in which it could best be used; devising means for its storage and handling, especially at airports; and adapting it to existing jet fuel systems. In September 1981, FAA sent its only four-engine jet, a Boeing 720, to NASA's Dryden Flight Research Facility in California to test the additive under operational conditions. The final step in the research, scheduled for some time in 1984, is to crash the 720 in the Mojave Desert under carefully controlled conditions.

To supplement its passenger screening program for deterring terrorism and sabotage aboard passenger aircraft, FAA conducts a comprehensive program to develop automatic detection of explosives hidden in lockers, checked baggage, and aircraft cargo holds. The principal technologies include x-ray absorption, thermal neutron activation, nuclear magnetic resonance, and vapor explosive detection. A new project was begun in 1981 for automatic detection of hidden explosives carried by persons walking past the detection instrument. Research also began toward counteracting the use of incendiary material as a hijacking weapon.

X-ray Absorption. The absorption technique employs an automatic computer-based analysis of the size, shape, and x-ray density of the checked baggage. Two prototypes of the system were modified during 1981 for operational use. One prototype, installed at Dulles International Airport, processed 65 000 pieces of baggage with satisfactory results. The other, delivered to the FAA Technical Center during the year, was in the midst of a two-year test using advanced computer programming techniques.

Thermal Neutron Activation. A device that detects explosives by the thermal neutron reactions peculiar to them was tested at the Pittsburgh and Boston International Airports and found promising. A more detailed testing program was planned.

Nuclear Magnetic Resonance. The resonance system relies on detecting the characteristic response of explosive molecules when subjected to magnetic and pulsed radio-frequency fields. At the end of 1981, it showed sufficient promise to justify converting the laboratory model into an operational system, to be ready for evaluation in 1982.

Explosives Vapor Detection. The first phase of a program for identifying vapors unique to different explosives was completed, and the vapor emission rates from various kinds of baggage determined. Specifications were being prepared for the development of a detector.

Walk-by Explosives Detector. Working with FAA, the DOT Transportation Systems Center in Cambridge began developing equipment to detect hidden explosives carried past it. A device was expected to be ready for laboratory test and evaluation by early 1982.

Countering Incendiary Liquids. The FAA Technical Center began a program to meet threats like those posed by Cuban hijackers in 1980 who threatened to ignite gasoline they brought aboard aircraft. One recommendation was the use of advanced fire extinguishers, particularly the Halon 1211. The center produced for loan to the airlines a 12-minute video tape showing the proper use of hand-held fire extinguishers including the Halon 1211.

Although a certain amount of FAA's medical safety research is done under contract, the bulk of it is done by the Office of Aviation Medicine in FAA headquarters and by the Civil Aeromedical Institute in Oklahoma City. This research identifies human factors that cause accidents, devises ways of preventing future accidents, and seeks to ensure that passengers can survive accidents that do occur.

The Neurological and Neurosurgical Report. A report prepared for the Office of Aviation Medicine by the American Medical Association in collaboration with the American Academy of Neurology and the American Association of Neurological Surgeons presented the "status and knowledge of neurological and neurosurgical conditions associated with aviation safety." The report alerted medical examiners to conditions that prima facie disqualified airmen from flying and indicated what to look for in permitting airmen to remain on or go back to flying status.

Air-Traffic-Controller Applicant Testing. FAA developed, validated, and put into use two new, customized, job-related tests for screening air-traffic-controller applicants. The multiplex controller-aptitude test teaches applicants a simplified version of the air traffic control rules, pictures simulated air traffic crossing a controller's display, and measures how well the applicants control that traffic in a time stress situation. Since most applicants have prior experience in aviation, some even as military air traffic controllers, FAA developed also an ATC test that measures important aspects of such knowledge. The tests were given students at both military and FAA air traffic controller schools, and performance was measured as students progressed through training and worked at operational sites. The new tests, which consistently produced higher correlations with success than did older testing devices, are expected to reduce greatly the percentage of controllers who fail training and improve the quality of those who pass. The tests were administered to some 125 000 applicants following the dismissal by President Reagan, in August, of 11 400 striking controllers.

Airport Pavement

In 1981, as in earlier years, roughly half the government funds allotted by FAA to the nation's airports under the Airport Development Aid Program (ADAP) went for airport pavement construction. FAA continued research to ensure the optimum condition of those pavements. Three principal research projects in 1981 were (1) establishing newer, more realistic construction criteria for high-volume traffic pavements; (2) studying ways to minimize the adverse effects of cold weather on pavement construction and performance; and (3) developing new techniques for improv-

ing aircraft braking on water-covered runways and a methodology to measure and relate runway conditions to braking performance.

The need for the first project had long been evident because the guidance followed in the construction and maintenance of pavements at the nation's busiest terminals is based on criteria developed for military airfields with relatively low traffic volumes in the 1940s and 1950s. Because of massive increases in traffic since that time, FAA, through the U.S. Army Corps of Engineers, is developing more realistic guidance specifically tailored for airports with runways subjected to more than 100 000 takeoffs and landings annually. At the Waterways Experiment Station of the Corps of Engineers in Vicksburg, Mississippi, testing pavements to destruction will document fatigue and failure of both rigid and flexible pavements.

The second project deals with the deleterious effects of frost and freezing in more than two-thirds of the country. In a five-year project—in its third year in 1981—FAA, the Federal Highway Administration, and the U.S. Army Cold Regions Research and Engineering Laboratory are developing design criteria to minimize the effects of freezing and thawing. The project seeks to provide stronger and more uniform pavements and to alert design engineers to methods and materials that will enable them to build pavements in the frost belt which, while costing no more than existing pavements, will have a much longer life. A predesign field test was being developed to indicate the degree of susceptibility of the sub-base to freezing.

The third project, the National Runway Friction Measurement Program, provided a way of automatically measuring the friction characteristics of airport pavements and of determining corrective action to provide enough friction to prevent aircraft skidding or hydroplaning. Using a portable mu-meter, a specially designed runway-friction-measurement device, FAA in September 1978 began evaluating surface conditions at 491 instrument-landing-system-equipped runways at 268 airports in the contiguous 48 states. The program, completed in October 1981, provided a fast and efficient way to ensure that airport pavements funded by ADAP had the characteristics needed to prevent hydroplaning in wet weather and slipping and skidding due to excessive rubber accumulation and ineffective grooving.

Environmental Research

In 1981, FAA worked in three principal areas of environmental research. The first, a continuing project, dealt with the effects of aircraft engine emissions at high altitudes. The second, also a continuing project, examined how best to control pollution in aircraft-engine emissions at low altitudes and on the ground.

The third studied how to handle and dispose of polychlorinated biphenyl (PCB), a colorless liquid chemical used as a dielectric in electrical equipment and determined to be a carcinogen.

The High-Altitude Pollution Program

HAPP originated as a follow-on investigation to the departmental Climatic Impact Assessment Program (CIAP), which had concluded that high-altitude commercial aircraft operations—including possible large-scale supersonic transport and subsonic operations—could significantly deplete atmospheric ozone, with attendant harm to man and the environment. The CIAP calculations were far from definitive, and HAPP was established to resolve uncertainties. HAPP's findings show that, as far as large-scale SST operations alone are concerned, CIAP's conclusion was essentially correct. If large-scale SST fleets become a reality, they will indeed deplete atmospheric ozone and harm the environment. But existing and future subsonic operations would generate additional ozone and thus partially or fully offset harmful effects of the SST fleets. The change in ozone would depend on the size of the respective fleets and the altitudes at which they operated. Large SST fleets would, in short, deplete the ozone layer; large subsonic fleets, recharge it. FAA's research was closely coordinated with that of NASA, the World Meteorological Organization, and the National Oceanic and Atmospheric Administration. The findings were to be submitted to Congress in January 1982.

Low-Altitude Pollution Control

The basic Clean Air Act of 1970 calls for the control of harmful aircraft-engine emissions at or near the ground. Although relatively little research had been done on this kind of pollution before that time, the Environmental Protection Agency (EPA) issued the first aircraft emission standards in 1973 on the basis of available information. The standards were to go into effect at future dates, and EPA stipulated that, should technical information in the interim warrant it, they would be changed accordingly. FAA research programs (some conducted with DoD, EPA, and NASA) and monitoring and modeling of actual airport pollution indicated by 1981 and in the years immediately preceding that the aircraft emission standards originally proposed by EPA were more stringent than required. EPA was withdrawing some standards and re-examining and revising others.

The PCB Problem

In 1978 EPA recognized that polychlorinated biphenyl, a liquid chemical, was carcinogenic. EPA's rule had allowed use of PCB-containing equipment provided the toxic fluid was below a certain concentra-

tion and was totally enclosed and could not escape. In early 1981, a private environmental group in a class action suit successfully challenged the rule. The court gave EPA time to work out ways PCB in existing equipment was to be used, handled, and disposed of safely. FAA, which has equipment containing the chemical, is working to ensure the safety of its equipment.

Air Navigation and Air Traffic Control

Mode S Radar Beacon Program

Mode S—a long-term program to develop advanced ground sensors and airborne transponders—in the next several years will begin replacing the existing air traffic control radar-beacon system (ATCRBS) as the primary tracking and surveillance system in FAA's automated control system.

FAA developed the Mode S radar system because ATCRBS has serious shortcomings, which became more apparent with the increasing traffic densities of the 1970s. Mode S sensors—advanced interrogators mounted on primary radar antennas—will be able to address individual Mode S transponders and aircraft equipped with a traffic-alert and collision-avoidance system (TCAS). Mode S receives a response from a specific aircraft by using that aircraft's unique identity code, rather than receiving signals from all the aircraft in the vicinity. It thus ends garbled and overlapping responses common on ATCRBS and provides a digital data link between each aircraft and the ground facility monitoring it. Deployment of Mode S sensors and transponders will significantly upgrade the existing, computerized, secondary surveillance radar system.

Conversion from ATCRBS to Mode S will be gradual. At the end of 1981, three Mode S models had been tested and evaluated at FAA's Technical Center, and FAA's operating services were to begin early procurement for possible operation by mid-1987.

Traffic-Alert and Collision-Avoidance System (TCAS)

A new, wholly airborne, air-to-air, midair collision-avoidance system, TCAS is designed to operate independently of the existing air traffic control system. It was designed from the beginning with a digitized, discrete-address, Mode S radar-beacon capability. TCAS-equipped aircraft will carry both Mode S antennas and Mode S transponders, to communicate with other similarly equipped planes and also with planes carrying conventional transponders.

Two basic versions of the new system are contemplated. TCAS-I is a low-cost system within the reach of most owners of general-aviation aircraft. It will provide the pilot a proximity warning—a visual or audible alarm alerting him that another aircraft carrying either TCAS-I or a conventional transponder is near.

The more capable and more expensive TCAS-II will protect against collision independently of the ground ATC system by using vertical maneuvers, with potential expansion to horizontal maneuvers should technical and economic feasibility be demonstrated.

FAA estimates that TCAS-I units can be in volume production in 36 months and TCAS-II in 48.

Microwave Landing System (MLS)

MLS—which will eventually replace the instrument landing system (ILS), the international standard precision landing aid since 1949—was developed by FAA in the early 1970s, using a time-referenced scanning-beam technique. It was accepted by the International Civil Aviation Organization as the international standard in 1978. Three versions of the system have been developed: a basic, wide-aperture system for large airports; a basic, narrow-aperture system for medium-size airports; and a small community system for smaller airports. By 1981, all three systems had been tested and evaluated.

At a meeting in Montreal in April 1981, ICAO agreed on the standards and recommended practices for MLS use in international civil aviation. ICAO also agreed to a first draft international plan for transition from the ILS to the MLS.

Meanwhile, FAA's operating services accepted the MLS technical data package, and FAA completed installation during 1981 of four MLS systems to be used in a service evaluation program. Two small commercial airlines, equipped with avionics supplied by FAA, would check out the guidance of the four units during a two-year test period. FAA planned to conduct tests and collect data for developing siting standards, terminal instrument procedures, and flight inspection and maintenance procedures.

Modernizing the Flight Service Stations

Replacement of the agency's long out-of-date and highly labor-intensive flight service stations by a centralized automated system began in earnest in early 1978. The present, revised master plan calls for consolidation of the nation's more than 300 stations into 61 automated hubs at airports in 45 states and Puerto Rico, chosen because of heavy general-aviation use. Equipped with computer terminals and cathode-ray-tube displays, the hubs would operate in conjunction with computers at air-route traffic control centers, which receive data from the FAA Weather Message Switching Center in Kansas City. Remote terminals tied in with the hubs would complete the service.

In early 1980, competitive contracts were awarded for the design of the automated system. In October 1981, the winner was awarded a contract to produce the computers as well as the rest of the system. Two models were to be produced. A basic model capable of

displaying weather and flight data in alphanumeric form on the specialist's screen was to be ready in two years. It would eventually be replaced by the more sophisticated model with additional displays for weather inputs, charts, and graphics, as well as access to the data base from remote computer terminals. By 1988, the system would be in full operation.

According to FAA estimates, meeting the demand for future flight services with the existing one-to-one manual system would require 11 500 flight specialists by 1995 and cost \$320 million per year. An automated system would require less than half that number of specialists and was expected to save the government millions of dollars by 1995.

New Automated Weather Stations

In 1980, FAA developed a follow-on system to its AV-WOS automated weather observation system for aviation, developed in 1978 with the National Weather Service. The new wind-altimeter and voice-equipped (WAVE) system responded to an FAA flight operations requirement for an automated, unmanned observation station to serve airports with approved instrument landing approaches. Industry developed two commercial WAVE systems in 1981, and FAA certified them for civil use.

WAVE was followed by yet another system. Using the basic modular WAVE, adding ceiling and visibility sensors, and enhancing the data processing capability, FAA and NWS developed a still more advanced automated facility for air taxis and commuter airlines. Two of these ALWOS low-cost weather observation systems were being tested as 1981 ended—one at Dulles International Airport, the other on an oil rig in the Gulf of Mexico.

Meanwhile, realizing an even more sophisticated automated flight-service station was needed, FAA in 1981 completed development of the automated

weather observation system (AWOS) by adding more weather sensors and sophisticated data processing equipment to the basic WAVE and ALWOS modular systems.

Next-Generation Weather Radar Network (NEXRAD)

The Departments of Transportation, Commerce, and Defense sponsor the NEXRAD program to develop a network of common-use, doppler weather radars that will meet the data needs of the nation's aviation in the 1990s and beyond. The new radars will replace the aging weather radar network operated by the National Weather Service with new and highly reliable, computer-linked, solid-state, doppler radar equipment capable of "seeing" inside storm clouds, spotting wind gusts, wind-shear, hail, and embryonic tornadoes, and providing a data service for civil and military aviation far superior to the existing network.

A joint NEXRAD special program office—in which the National Weather Service, working with FAA and the Department of Defense, has the lead role—was established in 1980. NEXRAD is a large development calling for 160 doppler radars, but by 1981 most outstanding issues had been agreed on. The design of the network and the builder will be decided by competition, and the National Weather Service in June 1981 spelled out the rules of competition for representatives of 50 interested companies. Invitations for bids for the design were issued in September 1981. Multiple contract awards for NEXRAD prototypes were to be made in the spring of 1982. Validation was to begin in 1983, and the winning company was to be selected in 1985 to build NEXRAD for the joint use of FAA, National Weather Service, and DoD. Final development was to be completed and production begun in 1986. Nationwide deployment was scheduled to start in 1987, with the entire network operating by 1990.

Environmental Protection Agency

The Environmental Protection Agency (EPA) and NASA continued the Interagency Energy/Environment (IEEP) studies during 1981. This cooperative activity extensively field-tested remote-sensing systems developed to gather data on hazy air masses and the transport and transformation of oxidants, aerosols, and other pollutants and compared the data gathered with those obtained by in situ measurement systems. The field studies focused on air pollution problems in the northeastern quadrant of the United States.

IEEP, begun in 1974 under EPA direction, provides state and federal regulatory decision-makers with environmental data and assessment methodologies to ensure that development of energy resources in the United States can be accelerated with acceptable impact on human health and the environment. NASA provided EPA space age technology for remotely sensing pollution and pollution effects. In particular, NASA contributed to the EPA study conducted during July-August 1980, known as PEPE/NEROS (Persistent Elevated Pollution Episode/North East Regional Oxidant Study), with its UV-DIAL (ultraviolet-differential absorption lidar) system for obtaining range-resolved ozone data from an airborne measurement platform. PEPE/NEROS collected an extensive set of data to improve knowledge of the origin, evolution, and movement of large-scale hazy air masses that occur frequently during the summer in the eastern half of the nation as a result of stagnant meteorological conditions.

Analysis of data obtained by NASA researchers for the PEPE/NEROS experiment continued during 1981. These data are being compared with similar data taken by other measurement techniques. The evaluated data sets will be transferred to EPA by late 1982.

In another major effort in 1981, NASA scientists helped evaluate remote and in situ sensors, particularly the UV-DIAL. Three experiments during July

and August demonstrated the performance of the UV-DIAL system for shorter distances and times. The experiments covered the altitude range from the surface to the upper troposphere, horizontal distances from one to a hundred kilometers, and times from minutes to several hours. Data collected will permit assessment of the accuracy, sensitivity, and precision of the UV-DIAL system.

Specific experiments were a study of the surface boundary layer of the atmosphere in a complex coastal environment, a case study of a theoretical mechanism for transporting ozone from the boundary layer up into the free troposphere above it via convective clouds, and measurement of the vertical structure of ozone and aerosols in the upper troposphere near the tropopause. Preliminary results showing the unique capabilities of the UV-DIAL system included:

- Measurement of micro-structure movement of aerosol-rich air up into the boundary layer as convective plumes penetrated these layers from below.
- Measurement in late evening of ozone and aerosol-rich air injected into the free troposphere above the convective boundary layer of an average afternoon.
- Measurement of ozone up to 13 km and aerosols up to 14 km and measurement of both horizontal and vertical structure of ozone and aerosols on the north side of the jet stream over Maine.

Imagery from geostationary meteorological satellites was used extensively for planning experiments and for real-time implementation. Several aspects of the 1981 experiments will assist EPA in completing the development and provide a data base for validating the EPA regional oxidant model. Finally, NASA began further development of the UV-DIAL system during 1981, to extend its application to measuring sulfur dioxide and to daylight operation.

National Science Foundation

The National Science Foundation supports research to advance scientific knowledge, including the fields of astronomy and atmospheric science. Scientists contribute to this research through NSF grants and the use of NSF-supported national research centers. In 1981, a number of discoveries in astronomy resulted from ground-based observations.

Two galaxies with the largest doppler redshifts ever detected were identified by researchers sponsored by NSF. Spectrum scans using the four-meter telescope of Kitt Peak National Observatory in Arizona and the three-meter telescope of the Lick Observatory in California revealed that the two galaxies were receding so rapidly that, according to the accepted expansion rate of the universe, they must lie at a distance of 10 billion light-years from Earth. Since their light would have required 10 billion years to reach Earth, astronomers have now looked more than halfway back to the moment believed to mark the creation of the universe.

While most bright spiral galaxies are only weak radio sources, a few are much stronger radio emitters than would be expected from their brightness at optical wavelengths. Maps made with the new very large array of the National Radio Astronomy Observatory in West Virginia have established that these rare radio-bright galaxies are undergoing gigantic bursts of star formation in their nuclei.

The presence of auroras in the atmosphere of Jupiter has been well documented by the spacecraft *Voyager 1*, *IUE*, and *Copernicus*. Such activity has

been observed from the ground for the first time by three astronomers working with the four-meter telescope at Kitt Peak and NASA's three-meter Infrared Telescope Facility in Hawaii.

A relatively new technique called very-long-baseline interferometry has enabled radio astronomers at the California Institute of Technology to obtain the first definite evidence of apparent faster-than-light, or superluminal, motion. Gas clouds were observed to move faster than the light barrier in three quasars and one galaxy. Since such speeds are forbidden by the theory of relativity, the phenomenon has been interpreted as a relativistic deflection of light emitted from material in rapid motion toward the observer.

A puzzling region of virtually empty space has been found 400 million light-years away in the constellation Bootes by three astronomers making a broad survey of galaxies with telescopes on Kitt Peak, Mount Hopkins in Arizona, and Palomar Mountain in California. By far the largest such void ever detected, it is 300 million light-years in diameter and has a volume of about one percent of the observable universe.

A new spiral arm on the fringes of our Milky Way galaxy has been discovered by two Rensselaer Polytechnic Institute researchers using the 11-meter telescope of the National Radio Astronomy Observatory. Because such arms are composed of molecular gas and dust associated with star-forming regions, this finding indicates that the extent of star formation in our galaxy is significantly greater than believed before.

Smithsonian Institution

The Smithsonian Institution contributes to the national space program through an integrated program of basic research and development in space science and astrophysics at its Smithsonian Astrophysical Observatory (SAO) in Cambridge, Massachusetts, and exhibits at its National Air and Space Museum (NASM) in Washington. Basic research at the Center for Earth and Planetary Studies at NASM also supports national goals.

Space Sciences

High-Energy Astrophysics

During 1981, reduction and analysis of data from *Einstein*, the second High Energy Astronomy Observatory (HEAO) satellite, dominated research. The x-ray telescope, the imaging proportional counter, and the high-resolution imaging detector carried on the satellite were designed and developed by Smithsonian scientists. Other *Einstein*-related activities emphasized mission planning and selection of instrument observation targets, conservation of the spacecraft's attitude-control gas until it was exhausted in April 1981, and continued direction of the guest investigator program. Among highlights of the year's *Einstein* research were the discovery of two galaxies showing strong x-ray activity but no optical activity, the detection of a probable underluminous x-ray-active nucleus in the nearby galaxy M81, and the discovery of limitations on the physical state of a confining medium for the emission-line clouds found in the outer regions of active Seyfert nuclei. Imaging instruments on *Einstein* have shown extended x-ray features associated with galaxies in the core of the galaxy cluster Abell 1367. These x-ray coronas may be hot gas gravitationally bound to the galaxies by massive envelopes of subluminous matter.

Einstein observations of galactic x-ray sources resulted in discovery of a diffuse source associated with the puzzling celestial object SS 433. From *Einstein* data on the Tycho supernova remnant, an accurate estimate was obtained of the mass ejected in the explosions, and the interaction of the expanding shell with the ambient interstellar medium was studied. Size and distribution of the "x-ray clouds" are being examined to learn more about the instabilities that fragment the expanding shell and about the role of these fragments

in the acceleration of the electrons producing the radio shell.

Other substantial data analysis activities included the *Heao 1*, Small Astronomy Satellite (*SAS 3*), and sounding rocket programs. The scanning modulation collimator on *Heao 1* led to significant scientific results, including discovery of x-ray or optical pulsations, or both, from two new celestial, cataclysmic variable systems, H2252-035 and V 1223 Sag, and identification of the first normal M-giant star (2A1704+241) as an x-ray emitting system. A study of x-ray background fluctuations on a small angular scale at energies above 6 kilo electron volts used data acquired by *SAS 3* (which operated from May 1975 to April 1979). A joint sounding rocket experiment developed by SAO and colleagues in France was reflown, measuring the soft x-ray spectrum of the North Polar Spur. Ultraviolet spectrometry of hot galaxies by the International Ultraviolet Explorer satellite *IUE* and theoretical interpretation of observations made by the Skylab Apollo telescope mount continued.

Balloon Astronomy

A balloon-borne, 102-centimeter, far-infrared telescope flown in October 1980 made new observations. The telescope—using a new, four-beam broadband photometer—was developed by SAO and the Naval Research Laboratory. During almost 10 hours of observation, 12 objects were observed, including 3 giant molecular-cloud regions. An unbiased, high-resolution, far-infrared survey of the galactic plane in the region of M17, covering more than seven square degrees and including the giant molecular cloud southwest of M17, detected 42 far-infrared sources. Thirteen lie within the M17SW giant molecular-cloud complex, and these data provided the first high-sensitivity, high-resolution, far-infrared survey of the complex.

The first far-infrared map of the evolved H II region M16 showed that the radiation arises primarily from interfaces of ionized gas and the molecular cloud. The observations have been important in understanding the latter stages of evolution of an H II region. A consistent picture of four stages is beginning to emerge: pre-main sequence, compact far-infrared, blister, and

diffuse. Far-infrared spectral observations of the Orion molecular cloud led to the detection of the rotational spectrum of shocked carbon monoxide in this region.

A balloon flight of a far-infrared spectrometer in December 1980 produced good-quality data on stratospheric spectra, but failed on astronomical spectra because of a balloon-system malfunction. The stratospheric observations were analyzed to detect minor species in the ozone-layer region and to obtain vertical mixing ratios—yielding an accurate measurement of the ratio of hydrogen fluoride to hydrogen chloride in the stratosphere.

Earth's Resources

The SAO Satellite-Tracking Network was upgraded with an improved optical-pulse chopper installed at all stations, to reduce laser pulse width and improve ranging accuracy. Data-handling capabilities were improved by modified software, allowing more direct transmission of data from field stations to SAO. All field stations continued local coverage of *Lageos*, *Geos 3*, and other satellites useful for geodetic research.

Studies of the geomagnetic variation in the thermosphere used data from several satellite-borne mass-spectrometer experiments. The work emphasized the latitudinal and local-time dependence of the variation, relation of specific features to the underlying energy sources, and determination of the time-lag between the onset of a geomagnetic disturbance and the corresponding disturbance in the atmosphere. The studies seek a better understanding of physical processes in thermospheric disturbance and the interactions with other atmospheric regions, as well as to provide an improved model for practical use.

Solar and Stellar Physics

Ultraviolet spectroscopic measurements by *IUE*, x-ray measurements by *Einstein*, and a solar-ultraviolet-coronagraph program provided the basis of observational research on the sun and other cool stars and stellar systems. Ultraviolet observing programs with *IUE* also included spectroscopy of supernova remnants, the interstellar medium, and cataclysmic variables.

Studies of mass loss in cool stars, using principally *IUE* observations, now indicate a consistent and continuous evolution of coronas, wind characteristics, and mass-loss rates. These vary from the hot fast winds of the sun with a low mass-loss rate, through the luminous hybrid stars exhibiting moderately hot winds, medium terminal velocities accompanied by larger mass loss, and finally to the coolest giant and supergiant stars possessing slow cool winds and high mass-loss rates.

Analysis of ultraviolet spectra obtained by *IUE* of two supernova remnants, the Cygnus Loop and the

Vela remnant, provided data on abundances of elements and on shock velocities. Ultraviolet spectra of AM Herculis stars in the low state and of the LMC transient x-ray source A9538–66 were obtained and analyzed.

New observational techniques were developed to study the acceleration of the solar wind out of the sun and the physics of the outer solar corona. Coronagraphic observations in April 1979 and February 1980 from sounding rockets carrying the new ultraviolet light coronagraph and a white light coronagraph led to the first measurements of coronal temperatures beyond 1.5 solar radii from the center of the sun. They are expected to determine upper limits on velocities of coronal material flowing out into the solar wind. New diagnostic techniques for determining many of the major plasma parameters of the solar-wind acceleration region are being developed, and an ultraviolet light coronagraph has been defined for a possible Shuttle Spacelab mission.

Rocket measurements of Lyman-alpha profiles showed that the hydrogen temperature decreased with height in three regions of the corona. Evidence was found for a small amount of proton heating and non-thermal contribution to the motions of coronal protons between 1.5 and 4 solar radii. The data also suggest that the solar-wind flow was subsonic in the observed regions.

Gravity Research

Research on use of hydrogen masers for scientific programs continued. SAO's hydrogen maser group provided the three masers used for deep space tracking in NASA's planetary Voyager program. Work to improve stability and support of the 14 VLG-series masers now in the field continued.

Lunar Research

A Smithsonian participant in the Lunar Highlands Initiative is leading a consortium to study the petrography, major and minor element chemistry, and ages of some of the lunar samples brought to earth by the *Apollo 16* mission. Effort is focused on rock 67015, a breccia with a light-gray, friable matrix from the rim of North Ray Crater. Thin sections will undergo optical and microprobe studies at SAO, and splits were sent to Washington University at St. Louis for trace-element (neutron activation) analyses and argon dating. Although this breccia appeared similar to others from the same site, early results of the study show that the matrix is more variable in a KREEP (a lunar material) component and the clasts include at least one variety not found in the adjacent breccias.

The discovery of a unique eucrite-like lunar gabbro among the coarse fines of an *Apollo 16* soil, 61220, also was reported.

Planetary Research

Voyager Studies

Investigations by a member of the Voyager imaging team detected planetary auroras, detected lightning and bright fireballs in the atmospheres of Jupiter and Saturn, and measured aerosol layers that exist well above the cloudtops of both planets. Studies of volcanism on Jupiter's satellite Io led to a model for the plumes that compares favorably with the observed examples. The model requires that the masses of solid and gaseous material must be roughly equal. In an observational and theoretical study of the photometric function of airless bodies, an accurate representation of the complete lunar phase curve was achieved. The surface structure of all the larger satellites of Jupiter and Saturn, save Titan, can now be analyzed.

Voyager results were analyzed in an investigation of the sources of the finely detailed features seen in the radial structure of Saturn's rings. Because several sources are likely, a detailed calculation of the location of resonances and their theoretical strengths is in progress. (However, perturbations associated with satellite resonances are clearly responsible for much detail in those parts of the ring where the optical thickness is not too large.) The structure in the outer ring A appears to have a clear association with several satellites, as does some but not all of the structure in ring C. At least two instances of satellite resonance unseen elsewhere are now clearly identified. These occur when

the local precession of the apsides (rotation of a line through the high and low points of the orbit) equals the orbital frequency of the satellite. Certain resonances now appear to be slightly displaced from their predicted positions by nontrivial ring mass. It is now clear that the two satellites (S 10 and 11) move in orbits differing in semimajor axis by about 50 kilometers—substantially less than the sum of their radii. Their mean motions differ by about 0.25° per day, and they will come close together about a year in the future.

Center for Earth and Planetary Studies (National Air and Space Museum)

Research was conducted in 1981 in photogeologic interpretations of the planets, terrestrial and planetary remote sensing, and comparative planetology. Lunar research concentrated on studies of orbital geochemical data and photogeology of impact basins and volcanic features. X-ray data for areas of large impact structures yielded information on primitive anorthositic crustal material underlying the surface.

Studies of ridge systems on Mars, on both a local and planet-wide scale, added to knowledge of Martian global tectonics and indicated the timing of geologic events in the Tharsis region. In comparative planetology, study of terrestrial deserts has had applications to the distribution, morphology, transport, and mineralogy of sand deposits and dunes on Mars.

International Communication Agency

The successes of two flights of the nation's Space Shuttle *Columbia* and the unmanned *Voyager 2* flight to Saturn and beyond were echoed around the world during 1981 by the United States International Communication Agency. USICA coverage included direct satellite TV and live radio broadcasts, feature stories, news coverage, exhibits, information materials, and video tapes for television.

USICA emphasized the U.S. commitment to advancing science and enlarging the frontiers of human knowledge through space exploration. It stressed U.S. leadership in space technology and the spin-off benefits for mankind. Worldwide reaction was positive. Perhaps as important as the news coverage was the provision of face-to-face contact for scientists, government leaders, academics, and citizens with the first crew of *Columbia*, astronauts Robert Crippen and John Young.

Space Shuttle

USICA placed the flight of *Columbia* on its worldwide Issues Agenda, to guide overseas posts in selected events for emphasis. A NASA film on the Shuttle was offered to posts. Both the April and November launches were covered live by USICA media, the agency facilitating the transmission by satellite to some 15 countries. Voice of America broadcast both launches live from Kennedy Space Center in nine languages and interviewed NASA officials and the astronauts. Advance information packets were supplemented by extensive coverage by the USICA press service to 193 posts in 125 countries. Agency magazines featuring *Columbia* on their covers were distributed in Africa and the Soviet Union. An agency pamphlet, *The Flight of Columbia*, was distributed in 73 000 Spanish, French, and English copies. TV news clips, as well as a

23-minute USICA video tape special, were distributed in Spanish, French, Portuguese, Arabic, Polish, and English. The 23-minute tape was also available via satellite to any country willing to cover the down-leg satellite charge. These productions used photographic and other material from NASA.

Exhibits on *Columbia* were popular during 1981. USICA posts in Japan, India, and Uganda asked for materials to produce an exhibit, and the Uganda show was transformed into a circulating exhibit in Africa following its showing in Kampala. Shuttle-related materials such as models, brochures, posters, and equipment for display (such as spacesuits and tiles from the orbiter) have been requested continuously by field posts, and a poster exhibit was one of this year's most requested items.

The first crew visited eight countries in Europe and Asia after the April mission, including the Paris Air Show in May. USICA programmed appearances, parades, and celebrations in Germany, Yugoslavia, The Netherlands, Spain, England, Ireland, Australia, and New Zealand. Exchanges with the public were also arranged for other NASA astronauts, in Indonesia, Thailand, Mexico, Liberia, Kenya, and Botswana.

Voyager 1 and 2

The *Voyager 1* flyby of Saturn in late 1980 was covered by agency magazines in early 1981. Wireless file coverage of the *Voyager 2* passage around Saturn was extensive and a 30-minute program for television was distributed in English and foreign languages. Additional magazine stories on the scientific achievements will be released in 1982. An exhibit, "Images from Space," also emphasizes the scientific results of the flight.

Appendixes

APPENDIX A-1

U.S. Spacecraft Record

(Includes spacecraft from cooperating countries launched by U.S. launch vehicles.)

Year	Earth Orbit ^a		Earth Escape ^a		Year	Earth Orbit ^a		Earth Escape ^a	
	Success	Failure	Success	Failure		Success	Failure	Success	Failure
1957	0	1	0	0	1970	36	1	3	0
1958	5	8	0	4	1971	45	2	8	1
1959	9	9	1	2	1972	33	2	8	0
1960	16	12	1	2	1973	23	2	3	0
1961	35	12	0	2	1974	27	2	1	0
1962	55	12	4	1	1975	30	4	4	0
1963	62	11	0	0	1976	33	0	1	0
1964	69	8	4	0	1977	27	2	2	0
1965	93	7	4	1	1978	34	2	7	0
1966	94	12	7	1 ^b	1979	18	0	0	0
1967	78	4	10	0	1980	16	4	0	0
1968	61	15	3	0	1981	20	1	0	0
1969	58	1	8	1	Total	977	134	79	15

^a The criterion of success or failure used is attainment of earth orbit or earth escape rather than judgment of mission success. "Escape" flights include all that were intended to go to at least an altitude equal to lunar distance from the earth.

^b This earth-escape failure did attain earth orbit and therefore is included in the earth-orbit success totals.

APPENDIX A-2

World Record of Space Launchings Successful in Attaining Earth Orbit or Beyond

(Enumerates launchings rather than spacecraft; some launches orbited multiple spacecraft.)

Year	United States	U.S.S.R.	France	Italy	Japan	People's Republic of China	Australia	United Kingdom	European Space Agency	India
1957		2								
1958	5	1								
1959	10	3								
1960	16	3								
1961	29	6								
1962	52	20								
1963	38	17								
1964	57	30								
1965	63	48	1							
1966	73	44	1							
1967	57	66	2	1			1			
1968	45	74								
1969	40	70								
1970	28	81	2	1 ^a	1	1				
1971	30	83	1	2 ^a	2	1		1		
1972	30	74		1	1					
1973	23	86								
1974	22	81		2 ^a	1					
1975	27	89	3	1	2	3				
1976	26	99			1	2				
1977	24	98			2					
1978	32	88			3	1				
1979	16	87			2			1		
1980	13	89			2					1
1981	18	97			3	1		2		2
Total	744	1436	10	8	20	9	1	1	3	3

^a Includes foreign launchings of U.S. spacecraft.

Successful U.S. Launches—1981

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
21 Feb. <i>Comstar D-4</i> 18A Atlas-Centaur	Objective: To place spacecraft in geosynchronous orbit to provide communications to 48 contiguous states, Alaska, Hawaii, and Puerto Rico. Spacecraft: Drum-shaped cylinder, 6.1 m long, 2.44 m in diameter. Can carry more than 14 000 2-way high-quality voice circuits. Weight at liftoff: 1484 kg.	35 794 35 782 1436.2 0.1	Last in series of 4 domestic communications satellites launched by NASA for Comsat General Corp. Leased to AT&T. Apogee-boost motor fired 23 Feb. Became operational 5 May. On station at 127° W. longitude over equator.
28 Feb. Defense 19A Titan IIIB-Agena D	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	285 138 88.5 96.4	Reentered 20 June.
16 Mar. Defense 25A Titan III	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	35 801 35 776 1436.2 1.3	Still in orbit.
12 Apr. Space Shuttle <i>Columbia</i> (STS 1) 34A	Objective: To demonstrate safe ascent and return of orbiter and crew. Space Shuttle consists of reusable orbiter <i>Columbia</i> (OV-102), external tank (ET), and 2 solid-fueled rocket boosters (SRBs). Orbiter is crew- and payload-carrying, delta-winged spacecraft about size of DC-9 aircraft, 37 m long with 24-m wing span, weighing 75 000 kg without fuel. Orbiter designed to transport payload of 29 500 kg into orbit when operational. Cargo bay measures 18.3 × 4.6 m. Three main, liquid-fueled rocket engines, each with 1670-kilonewton thrust at sea level. Engines fed propellants from external tank 47 m long, 8.4 m in diameter, holding 719 000 kg liquid hydrogen and liquid oxygen. External tank, only part of Shuttle not reusable, was jettisoned just before orbit. Solid rocket boosters—each 45.5 m long, 3.8 m in diameter, with 23 575 kilonewton combined thrust—dropped away after ascent and were recovered for reuse. Payload: development flight instrumentation.	250 238 89.4 40.4	First of 4 planned orbital flight tests of Space Transportation System. Piloted by astronauts John W. Young and Robert L. Crippen. Shuttle lifted off from KSC at 7:00:03 a.m. EST. After <i>Columbia</i> entered orbit, cargo bay doors were tested in space environment. Integrity of thermal protection system (TPS) was proved under reentry heating and stress. First use of both liquid- and solid-fueled rocket engines for launch of manned mission; first airplane-like landing of craft from orbit. Touched down on runway 23, Edwards AFB, Calif., 10:20:58 a.m., PST, 14 Apr. Total mission time: 2 days 6 hrs 20 min 52 sec. Orbiter was returned to KSC 28 Apr. for refurbishment for November flight.
24 Apr. Defense 38A Titan IIIB-Agena D	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	708 188 93.0 62.7	Still in orbit.
15 May <i>Nova 1</i> 44A Scout	Objective: To launch spacecraft into elliptical orbit for transfer into circular orbit, to enable Navy to provide worldwide positional data to military and commercial users. Spacecraft: Octagonal body 52 cm in diameter, 39 cm high, topped by cylindrical attitude control section 27 cm in diameter, 76 cm high. Dual 5-MHz oscillators, phase modulators, and transmitters operating at 400 and 150 MHz. Computer with memory for 5-day messages, 50- to 1300-bps readout. Command system. Digital telemetry capacity of 172 channels. Power supplied by 4 panels of solar cells, 1 battery pack. Attitude control system includes 8-cm dual scissor boom, 66-cm extendable boom. Weight at liftoff: 167 kg.	931 351 97.5 90.2	First of series of improved satellites launched by NASA for TRANSIT, Navy Navigation Satellite System. Still in orbit.

Successful U.S. Launches—1981

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
22 May <i>Goes 5</i> 49A Thor-Delta	Objective: To launch spacecraft into geosynchronous orbit to provide near-continual, high-resolution, visual and infrared imaging over North and South America and surrounding oceans; to continue demonstration and validation of temperature and moisture soundings from the VISSR atmospheric sounder (VAS). Spacecraft: Cylindrical, 2.15 m in diameter and 4.43 m long from top of S-band omni antenna rod to bottom of apogee-boost motor. Apogee-boost motor ejected after synchronous orbit reached. Primary structural member is thrust tube in center of cylinder. Visible infrared spin-scan radiometric atmospheric sounder (VAS) extends length of spacecraft, located in and supported by thrust tube. Scanning mirror at one end of thrust tube. Weight at liftoff: 837 kg. Weight in orbit, after ejection of apogee-boost motor: 444 kg.	35 792 35 783 1436.2 0.1	Second of 3 satellites to replace initial 3 operational satellites. Launched by NASA for National Oceanic and Atmospheric Administration, <i>Goes 5</i> is 5th in series of operational spacecraft funded by NOAA. Apogee-boost motor fired 24 May. Satellite placed in synchronous orbit at 75° W. longitude. Turned over to NOAA 2 July; became operational 5 Aug.
23 May <i>Intelsat V F-1</i> 50A Atlas-Centaur	Objective: To place spacecraft in geosynchronous orbit for INTELSAT, provide 12 000 voice circuits plus 2 television channels simultaneously. Spacecraft: Modular main body, 1.66 × 2.01 × 1.77 m, with winglike solar arrays spanning 15.6 m. Overall height, 6.4 m; width deployed, 6.8 m; 6 communications antennas—2 global-coverage horns, 2 hemispherical/zone offset-fed reflectors, and 2 offset-fed spot-beam reflectors. Double the capacity of Intelsat IVA series. Weight at launch: 1928 kg.	35 803 35 773 1436.2 0.1	Second in series of 9 satellites; launched by NASA for 106-member-nation International Telecommunications Satellite Organization (INTELSAT). Placed in geosynchronous orbit after apogee motor firing 25 May. Satellite moved to operational position at 24.5° W. longitude. Satellite turned on 14 July.
23 June <i>Noaa 7</i> 59A Atlas F	Objective: To launch spacecraft into sun-synchronous orbit of sufficient accuracy to enable spacecraft to make dependable daytime and nighttime meteorological observations of the earth. Spacecraft: Launch configuration including apogee-kick motor, 3.7 m high, 1.9 m in diameter. Solar panels deploy in orbit. Structure composed of 4 major elements: reaction-control-equipment support structure (RSS); equipment support module (ESM); instrument monitoring platform (IMP); and solar array. With exception of IMP and transition ring, basic structure identical to DMSP block 5D2. Instruments include advanced very-high-resolution radiometer (AVHRR), data-collection and location system (DCS), space environment monitor (SEM), total energy detector (TED), medium-energy proton-electron detector (MEPED), high-energy proton-alpha detector (HEPAD), contamination monitor, and Tiros operational vertical sounder (TOVS) composed of 3 instruments: high-resolution infrared-radiation sounder (HIRS/2), stratospheric sounding unit (SSU), and microwave sounding unit (MSU). Weight in orbit after apogee motor firing: 723 kg.	858 838 101.9 98.9	Third in series of operational environment monitoring satellites; launched by NASA for National Oceanic and Atmospheric Administration. Joined <i>Noaa 6</i> in orbit as part of 2-satellite operational system. Apogee motor fired 23 June. Turned over to NOAA 13 July, became operational 24 Aug.

Successful U.S. Launches—1981

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
3 Aug. <i>Dynamics Explorer 1</i> (DE 1) 70A Thor-Delta	Objective: To study interaction between earth's magnetosphere, ionosphere, and atmosphere in higher region than DE 2. Spacecraft: 16-sided body, 1.4 m wide, 1.1 m high. Satellite structure provides mounting surfaces for outer shells, experiments, electronic packages, attitude control systems, S-band antenna, and launch adapter. Weight: 424 kg including 105 kg of instruments.	24 770 671 437.8 90.0	Dual launch placed NASA's DE 1 and DE 2 in polar, coplanar orbits. Minimum scientific lifetime of 1 year planned for both spacecraft. Mission success relies on correlative sets of measurements from 2 satellites. Final orbits somewhat lower than predicted, but suitable to carry out full scientific mission. Both spacecraft operating properly and returning data. Returned first color views from space of auroras at North and South Poles.
<i>Dynamics Explorer 2</i> (DE 2) 70B	Objective: To study interaction between earth's magnetosphere, ionosphere, and atmosphere in lower region than DE 1. Spacecraft: 16-sided body, 1.4 m wide, 1.1 m high. Satellite structure provides mounting surfaces for outer shells, experiments, electronic packages, attitude control systems, S-band antenna, and launch adapter. Weight: 420 kg including 111 kg of instruments.	1 002 304 97.8 90.0	Dual launch orbited DE 1 and DE 2 (see above).
6 Aug. <i>Fisatcom 5</i> 73A Atlas-Centaur	Objective: To place spacecraft in synchronous, near-equatorial orbit for USAF narrow-band and wideband communications and USN fleet-relay and broadcast channels. Spacecraft: Hexagonal, composed of payload module and spacecraft module; 6.7 m high. Provides 1 SHF and 23 UHF communications channels. Weight at lift-off: 1876 kg. Weight after apogee-motor firing: 1005 kg.	36 814 34 774 1436.5 6.2	Fifth of 5 planned satellites; launched by NASA for Navy, to serve DoD. Satellite providing limited communications after structural damage received during orbital insertion.
3 Sept. Defense 85A Titan IIID	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	521 212 91.8 96.9	Still in orbit.
24 Sept. SBS 2 96A Thor-Delta	Objective: To place satellite in stationary geosynchronous orbit to provide integrated, all-digital, interference-free transmission of telephone, computer, electronic mail, and video teleconferencing to SBS business clients. Spacecraft: cylindrical, 2.2 m in diameter, with stowed height at launch of 2.8 m; height in orbit, 6.6 m with solar panel and antenna deployed. Spin-stabilized. Provides up to 480 million bits of data per second, equivalent of more than 10 million words. Two nickel-cadmium batteries provide power during eclipse. Weight after apogee-motor firing: 555 kg.	35 791 35 783 1436.1 0.1	Second of 4 domestic communications satellites built for Satellite Business Systems (SBS); launched by NASA. Apogee-kick motor fired 26 Sept. Spacecraft placed in synchronous orbit at 97° W. longitude. Commercial operations began 15 Dec.
6 Oct. SME 100A Thor-Delta	Objective: To study reactions between sunlight, ozone, and other chemicals in atmosphere and how concentrations of ozone are transported in the region from 30-to 90-km altitude. Spacecraft: Satellite body is cylindrical, 1.7 m high and 1.25 m in diameter. Spacecraft powered by disk-shaped solar array 2.2 m in diameter, affixed to lower end of main cylinder. Two nickel-cadmium batteries provide power during occultation and for high-power use. Satellite spin-stabilized. Weight: 145 kg.	534 530 95.3 97.5	Dual launch orbited NASA's Solar Mesosphere Explorer and UOSAT (below). All SME systems performing properly. Instruments returning data for first comprehensive global study of creation and destruction of ozone. One-year mission planned, orbital lifetime of spacecraft expected to be about 3 years before reentry.

Successful U.S. Launches—1981

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
<i>UOSAT (Oscar 9)</i> 100B	Objective: To provide radio amateurs and educational institutions with operational satellite that can be used with minimal ground station for studying ionosphere and radio propagation conditions. Spacecraft: Rectangular, 42.5 cm square, 83.5 cm high. Weight: 50.4 kg.	533 531 95.3 97.5	United Kingdom amateur scientific satellite developed by University of Surrey, launched by NASA as secondary payload with <i>SME</i> . First Oscar designed to transmit scientific data and pictures of earth's surface for display on domestic TV set. Initial difficulty due to interference from 145-MHz telemetry transmitter was overcome by shift to redundant 435-MHz command system.
31 Oct. Defense 107A Titan IIIC	Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced.	382 134 90.4 29.3	Still in orbit.
12 Nov. Space Shuttle <i>Columbia</i> (STS 2) 111A	Objective: To demonstrate reusability of orbiter; launch, in-orbit, and entry performance under conditions more demanding than for STS 1; orbiter capability to support scientific and applications research with attached payload; and remote manipulator system (RMS). Space Shuttle consists of reusable orbiter <i>Columbia</i> (OV-102), external tank (ET), and 2 solid-fueled rocket boosters (SRBs). Payload: OSTA 1, consisting of Shuttle imaging radar (SIR-A), Shuttle multispectral infrared radiometer (SMIRR), ocean color experiment (OCE), measurement of air pollution from satellites (MAPS) experiment, feature identification and location experiment (FILE), nighttime and daylight optical survey of thunderstorm lightning (NOSL), and Heflex bioengineering test (HBT). OSTA 1 mounted on engineering-model pallet supplied by European Space Agency (ESA), part of joint NASA-ESA Spacelab program. Payload pointed toward earth. Weight of OSTA 1 and pallet: 2452 kg. RMS to deploy and retrieve payloads and accomplish other freight-handling activities. Mechanical arm jointed like human arm; fully extended, 15.3 m long, 38 cm in diameter. Weight of RMS: 408 kg. Additional payload cargo: development flight instrumentation (DFI), induced environment contamination monitor (IECM), aerodynamic coefficient identification package (ACIP), and passive orbiter experiments (OEX)—OEX tile-gap heating effects, OEX catalytic-surface effects, and OEX dynamic, acoustic, and thermal experiments. Weight: 6370 kg.	231 222 89.0 38.0	Second of 4 planned orbital flight tests of Space Transportation System. <i>Columbia</i> , piloted by astronauts Joe H. Engle and Richard H. Truly, lifted off from KSC at 10:10 a.m. EST. After Shuttle entered orbit, fuel-cell problem shortened planned 5-day mission to minimal mission of 36 orbits. OSTA 1 experiments returned good data. Remote manipulator arm, checked out in orbit, performed well except could not be cradled in backup mode. <i>Columbia</i> touched down on runway 23, Edwards AFB, Calif., 1:23:11 p.m. PST, 14 Nov. Total mission time: 2 days 6 hrs 13 min 11 sec. Orbiter returned to KSC 25 Nov. for refurbishment for next flight.

Successful U.S. Launches—1981

Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle	Mission Objectives, Spacecraft Data	Apogee and Perigee (km), Period (min), Inclination to Equator (°)	Remarks
20 Nov. <i>RCA-Satcom 3-R</i> 114A Thor-Delta	Objective: To place spacecraft in stationary geosynchronous orbit to provide television, voice channels, and high-speed data transmission to Hawaii, Alaska, Puerto Rico, and contiguous U.S.; to provide video programming to CATV (cable television) systems throughout U.S. Spacecraft: Box-shaped, 1.2 × 1.2 × 1.6 m high; 2 rectangular solar panels on short booms. Hydrazine-propellant tanks protrude from east and west panels of spacecraft body. Three-axis stabilized. Weight at launch: 1082 kg.	35 794 35 779 1436.1 0.1	Fourth in a series of RCA commercial communications satellites. Launched by NASA into transfer orbit. <i>RCA-Satcom 3-R</i> to replace <i>RCA-Satcom 3</i> lost in space in late 1979. Satellite moved to position at 131° W. longitude.
15 Dec. <i>Intelsat V F-3</i> 119A Atlas-Centaur	Objective: To place spacecraft in geosynchronous orbit for INTELSAT, provide 12 000 voice circuits plus 2 television channels simultaneously. Spacecraft: Modular main body, 1.66 × 2.01 × 1.77 m, with winglike solar arrays spanning 15.6 m. Overall height: 6.4 m; width deployed, 6.8 m; 6 communications antennas—2 global-coverage horns, 2 hemispherical/zone offset-fed reflectors, and 2 offset-fed spot-beam reflectors. Double the capacity of Intelsat IVA series. Weight at launch: 1928 kg.	36 001 35 690 1439.1 0.3	Third in series of 9 satellites, launched by NASA for 106-member-nation International Telecommunications Satellite Organization (INTELSAT). Apogee-kick motor fired 18 Dec., placing satellite in near geosynchronous orbit. Satellite to be stationed at 25° W. longitude.

U.S.-Launched Applications Satellites 1976-1981

Date	Name	Launch Vehicle	Remarks
COMMUNICATIONS			
17 Jan. 1976	CTS 1	Thor-Delta (TAT)	Canadian-U.S., most powerful experimental satellite.
30 Jan. 1976	Intelsat IVA F-2	Thor-Delta (TAT)	Second of series with double capacity of predecessors. Positioned over Atlantic.
19 Feb. 1976	Marisat 1	Thor-Delta (TAT)	For maritime use by Comsat, over Atlantic.
15 Mar. 1976	LES 8, LES 9	Titan IIIC	Experimental satellites with radioisotope power sources.
26 Mar. 1976	RCA-Satcom 2	Thor-Delta (TAT)	Second of 3 launched for RCA.
22 Apr. 1976	NATO IIIA	Thor-Delta (TAT)	First of new series.
13 May 1976	Comstar D-1	Atlas-Centaur	Placed over Pacific for AT&T by Comsat.
10 June 1976	Marisat 2	Thor-Delta (TAT)	For maritime use by Comsat, over Pacific.
8 July 1976	Palapa 1	Thor-Delta (TAT)	Indonesian domestic communications.
22 July 1976	Comstar D-2	Thor-Delta (TAT)	Placed south of United States for AT&T by Comsat.
14 Oct. 1976	Marisat 3	Thor-Delta (TAT)	Placed over Indian Ocean.
28 Jan. 1977	NATO IIIB	Thor-Delta (TAT)	Second of new series.
10 Mar. 1977	Palapa 2	Thor-Delta (TAT)	Indonesian domestic communications.
12 May 1977	DSCS II-7,8	Titan IIIC	Defense communications (dual launch).
26 May 1977	Intelsat IVA F-4	Atlas-Centaur	Positioned over Atlantic.
25 Aug. 1977	Sirio	Thor-Delta (TAT)	Italian experiment.
15 Dec. 1977	Sakura	Thor-Delta (TAT)	Japanese experiment.
7 Jan. 1978	Intelsat IVA F-3	Atlas-Centaur	Positioned over Indian Ocean.
9 Feb. 1978	Filtsatcom 1	Atlas-Centaur	First of new Defense series.
5 Mar. 1978	Oscar 8	Thor-Delta (TAT)	Secondary payload with Landsat 3, replacement for Oscar 6 for amateur radio communications.
31 Mar. 1978	Intelsat IVA F-6	Atlas-Centaur	Positioned over Indian Ocean.
7 Apr. 1978	BSE (Yuri)	Thor-Delta (TAT)	Japanese experimental direct-broadcast satellite for television; domestic satellite.
11 May 1978	OTS 2	Thor-Delta (TAT)	European Space Agency experimental relay satellite; domestic satellite.
29 June 1978	Comstar D-3	Atlas-Centaur	Positioned south of U.S. over the equator by Comsat; domestic satellite.
19 Nov. 1978	NATO IIIC	Thor-Delta (TAT)	Final one of this military series.
14 Dec. 1978	DSCS II-11,12	Titan IIIC	Defense communications (dual launch).
16 Dec. 1978	Anik 4 (Telesat D)	Thor-Delta (TAT)	Launched for Canada; domestic satellite.
4 May 1979	Filtsatcom 2	Atlas-Centaur	Second of new DoD series.
9 Aug. 1979	Westar 3	Thor-Delta (TAT)	Launched for Western Union Co. as part of its domestic communications links.
21 Nov. 1979	DSCS II-13,14	Titan IIIC	Defense communications (dual launch).
2 Dec. 1979	RCA-Satcom 3	Thor-Delta (TAT)	Launched for RCA, but contact lost during orbit circularization.
18 Jan. 1980	Filtsatcom 3	Atlas-Centaur	Third of DoD series.
31 Oct. 1980	Filtsatcom 4	Atlas-Centaur	Fourth of DoD series.
15 Nov. 1980	SBS 1	Thor-Delta (TAT)	Launched for Satellite Business Systems as part of its domestic communications links.
6 Dec. 1980	Intelsat V F-2	Atlas-Centaur	First of new series, positioned over Atlantic.
21 Feb. 1981	Comstar D-4	Atlas-Centaur	Fourth in series for Comsat General Corp.
23 May 1981	Intelsat V F-1	Atlas-Centaur	Second in series for INTELSAT, positioned over Atlantic.
6 Aug. 1981	Filtsatcom 5	Atlas-Centaur	Fifth in DoD series.
24 Sept. 1981	SBS 2	Thor-Delta (TAT)	Second in series for Satellite Business Systems.
20 Nov. 1981	RCA-Satcom 3-R	Thor-Delta (TAT)	Fourth in series for RCA, replacement for RCA-Satcom 3.
15 Dec. 1981	Intelsat V F-3	Atlas-Centaur	Third in series. To be positioned over Atlantic.
WEATHER OBSERVATION ^a			
29 July 1976	Noaa 5 (ITOS-H)	Thor-Delta (TAT)	Second-generation operational satellite for NOAA.
16 June 1977	Goes 2	Thor-Delta (TAT)	Second in series of operational synchronous-orbit satellites for NOAA.
14 July 1977	Himawari	Thor-Delta (TAT)	Japanese geosynchronous satellite.
23 Nov. 1977	Meteosat	Thor-Delta (TAT)	European Space Agency geosynchronous satellite.
1 May 1978	AMS 3	Thor-Burner 2	DoD meteorological satellite.
16 June 1978	Goes 3	Thor-Delta (TAT)	Third of this series for NOAA.
13 Oct. 1978	Tiros-N	Atlas F	First of third-generation for NOAA, also experimental satellite for NASA.
24 Oct. 1978	Nimbus 7	Thor-Delta (TAT)	Last of this experimental series for NASA.
6 June 1979	AMS-4	Atlas F	DoD meteorological satellite.
27 June 1979	Noaa 6	Atlas F	Second of 8 planned third-generation satellites for NOAA; first was Tiros-N.
29 May 1980	Noaa-B	Atlas F	Failed to achieve useful orbit.
9 Sept. 1980	Goes 4	Thor-Delta (TAT)	Fourth of this series for NOAA.
22 May 1981	Goes 5	Thor-Delta (TAT)	Fifth of polar-orbiting series for NOAA.
23 June 1981	Noaa 7	Atlas F	Replacement for Noaa-B.

^a Does not include Department of Defense weather satellites that are not individually identified by launch.

U.S.-Launched Applications Satellites 1976-1981

Date	Name	Launch Vehicle	Remarks
EARTH OBSERVATION			
5 Mar. 1978	Landsat 3	Thor-Delta (TAT)	Third experimental earth resources satellite.
26 Apr. 1978	HCMM (AEM 1)	Scout	Experimental, low-cost, limited-function heat-capacity mapping mission for earth resources.
27 June 1978	Seasat 1	Atlas F	Proof-of-concept oceanographic-phenomena data-collection satellite.
GEODESY			
9 Apr. 1975	Geos 3	Thor-Delta (TAT)	To measure geometry and topography of ocean surface.
4 May 1976	Lageos	Thor-Delta (TAT)	Laser geodynamic satellite.
NAVIGATION			
12 Oct. 1975	TIP 2	Scout	Transit Improvement Program.
1 Sept. 1976	TIP 3	Scout	Transit Improvement Program.
23 June 1977	NTS 2	Atlas F	Forerunner of Navstar Global Positioning System.
28 Oct. 1977	Transit	Scout	Developmental model.
22 Feb. 1978	Navstar 1	Atlas F	Global Positioning System satellite.
13 May 1978	Navstar 2	Atlas F	Global Positioning System satellite.
7 Oct. 1978	Navstar 3	Atlas F	Global Positioning System satellite.
11 Dec. 1978	Navstar 4	Atlas F	Global Positioning System satellite.
9 Feb. 1980	Navstar 5	Atlas F	Global Positioning System satellite.
26 Apr. 1980	Navstar 6	Atlas F	Global Positioning System satellite.
15 May 1981	Nova 1	Scout	First of improved Transit system satellites, for DoD.

APPENDIX B-2

U.S.-Launched Scientific Satellites 1976-1981

Date	Name	Launch Vehicle	Remarks
15 Mar. 1976	Solrad HiA, HiB	Titan IIIC	Measure radiation and particles at close to 120 000-km circular orbit.
22 May 1976	P-76-5	Scout	Plasma effects on radar and communications.
8 July 1976	SESP 74-2	Titan IIID	Particle measurements up to 8000 km.
20 Apr. 1977	Geos	Thor-Delta (TAT)	European Space Agency, study of magnetic and electric fields from geosynchronous orbit (not attained).
12 Aug. 1977	Heao 1	Atlas-Centaur	X-ray and gamma-ray astronomy.
22 Oct. 1977	ISEE 1,2	Thor-Delta (TAT)	Magnetosphere and solar wind measurements (for NASA and European Space Agency respectively).
26 Jan. 1978	IUE	Thor-Delta (TAT)	Ultraviolet observation of astronomical phenomena, in elliptical geosynchronous orbit.
14 July 1978	Geos 2	Thor-Delta (TAT)	European studies of magnetosphere, in geosynchronous orbit.
12 Aug. 1978	ISEE 3	Thor-Delta (TAT)	International Sun-Earth Explorer, in halo orbit near Earth-Sun libration point.
24 Oct. 1978	Cameo	Thor-Delta (TAT)	Barium and lithium cloud experiments, carried in rocket body of Nimbus 7 launcher.
13 Nov. 1978	Heao 2	Atlas-Centaur	High-resolution observations of astronomical x-ray sources.
30 Jan. 1979	Scatha	Thor-Delta (TAT)	Measurement of sources of electric charge buildup on spacecraft.
18 Feb. 1979	Sage	Scout	Measurement of stratospheric aerosols and ozone.
24 Feb. 1979	Solwind	Atlas F	Measurement of solar wind, electron buildup in polar regions, aerosols, and ozone.
6 June 1979	Ariel 6	Scout	Measurement of cosmic radiation (United Kingdom payload).
20 Sept. 1979	Heao 3	Atlas-Centaur	Gamma and cosmic ray emissions.
30 Oct. 1979	Magsat	Scout	Detailed current description of earth's magnetic field and of sources of variations.
14 Feb. 1980	SMM	Thor-Delta (TAT)	Solar Maximum Mission.
3 Aug. 1981	Dynamics Explorers 1, 2	Thor-Delta (TAT)	Measure magnetospheric-ionospheric energy coupling, electric currents and fields, plasmas.
6 Oct. 1981	SME	Thor-Delta (TAT)	Solar Mesosphere Explorer to measure changes in mesospheric ozone.
6 Oct. 1981	UOSAT (Oscar 9)	Thor-Delta (TAT)	Secondary payload with SME, for amateur radio and science experiments.

U.S.-Launched Space Probes 1975-1981

Date	Name	Launch Vehicle	Remarks
20 Aug. 1975	Viking 1	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Chryse, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of atmosphere.
9 Sept. 1975	Viking 2	Titan IIIE-Centaur	Lander descended, landed safely on Mars on Plains of Utopia, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of the atmosphere.
15 Jan. 1976	Helios 2	Titan IIIE-Centaur	Flew in highly elliptical orbit to within 41 million km of sun, measuring solar wind, corona, electrons, and cosmic rays. Payload had same West German and U.S. experiments as Helios 1 plus cosmic-ray burst detector.
20 Aug. 1977	Voyager 2	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Swung around Jupiter in July 1979, arrived Saturn in 1981, going on to Uranus by 1986.
5 Sep. 1977	Voyager 1	Titan IIIE-Centaur	Jupiter and Saturn flyby mission. Passing Voyager 2 on the way, swung around Jupiter in Mar. 1979, arrived at Saturn in Nov. 1980, headed for outer solar system.
20 May 1978	Pioneer Venus 1	Atlas-Centaur	Venus orbiter; achieved Venus orbit 4 Dec., returning imagery and data.
8 Aug. 1978	Pioneer Venus 2	Atlas-Centaur	Carried 1 large, 3 small probes plus spacecraft bus; all descended through Venus atmosphere 9 Dec., returned data.

U.S. and Soviet Manned Spaceflights 1961-1981

Spacecraft	Launch Date	Crew	Flight Time (days : hrs : min)	Highlights
Vostok 1	12 Apr. 1961	Yuriy A. Gagarin	0 : 1 : 48	First manned flight.
Mercury- Redstone 3	5 May 1961	Alan B. Shepard, Jr.	0 : 0 : 15	First U.S. flight; suborbital.
Mercury- Redstone 4	21 July 1961	Virgil I. Grissom	0 : 0 : 16	Suborbital; capsule sank after landing; astronaut safe.
Vostok 2	6 Aug. 1961	German S. Titov	1 : 1 : 18	First flight exceeding 24 h.
Mercury-Atlas 6	20 Feb. 1962	John H. Glenn, Jr.	0 : 4 : 55	First American to orbit.
Mercury-Atlas 7	24 May 1962	M. Scott Carpenter	0 : 4 : 56	Landed 400 km beyond target.
Vostok 3	11 Aug. 1962	Andriyan G. Nikolayev	3 : 22 : 25	First dual mission (with Vostok 4).
Vostok 4	12 Aug. 1962	Pavel R. Popovich	2 : 22 : 59	Came within 6 km of Vostok 3.
Mercury-Atlas 8	3 Oct. 1962	Walter M. Schirra, Jr.	0 : 9 : 13	Landed 8 km from target.
Mercury-Atlas 9	15 May 1963	L. Gordon Cooper, Jr.	1 : 10 : 20	First U.S. flight exceeding 24 h.
Vostok 5	14 June 1963	Valeriy F. Bykovskiy	4 : 23 : 6	Second dual mission (with Vostok 6).
Vostok 6	16 June 1963	Valentina V. Tereshkova	2 : 22 : 50	First woman in space; within 5 km of Vostok 5.
Voskhod 1	12 Oct. 1964	Vladimir M. Komarov Konstantin P. Feoktistov Boris G. Yegorov	1 : 0 : 17	First 3-man crew.
Voskhod 2	18 Mar. 1965	Pavel I. Belyayev Aleksey A. Leonov	1 : 2 : 2	First extravehicular activity (Leonov, 10 min).
Gemini 3	23 Mar. 1965	Virgil I. Grissom John W. Young	0 : 4 : 53	First U.S. 2-man flight; first manual maneuvers in orbit.
Gemini 4	3 June 1965	James A. McDivitt Edward H. White II	4 : 1 : 56	21-min extravehicular activity (White).
Gemini 5	21 Aug. 1965	L. Gordon Cooper, Jr. Charles Conrad, Jr.	7 : 22 : 55	Longest-duration manned flight to date.
Gemini 7	4 Dec. 1965	Frank Borman James A. Lovell, Jr.	13 : 18 : 35	Longest-duration manned flight to date.
Gemini 6-A	15 Dec. 1965	Walter M. Schirra, Jr. Thomas P. Stafford	1 : 1 : 51	Rendezvous within 30 cm of Gemini 7.
Gemini 8	16 Mar. 1966	Neil A. Armstrong David R. Scott	0 : 10 : 41	First docking of 2 orbiting spacecraft (Gemini 8 with Agena target rocket).
Gemini 9-A	3 June 1966	Thomas P. Stafford Eugene A. Cernan	3 : 0 : 21	Extravehicular activity; rendezvous.
Gemini 10	18 July 1966	John W. Young Michael Collins	2 : 22 : 47	First dual rendezvous (Gemini 10 with Agena 10, then Agena 8).
Gemini 11	12 Sept. 1966	Charles Conrad, Jr. Richard F. Gordon, Jr.	2 : 23 : 17	First initial-orbit docking; first tethered flight; highest earth-orbit altitude (1372 km).
Gemini 12	11 Nov. 1966	James A. Lovell, Jr. Edwin E. Aldrin, Jr.	3 : 22 : 35	Longest extravehicular activity to date (Aldrin, 5 h 37 min).
Soyuz 1	23 Apr. 1967	Vladimir M. Komarov	1 : 2 : 37	Cosmonaut killed in reentry accident.
Apollo 7	11 Oct. 1968	Walter M. Schirra, Jr. Donn F. Eisele R. Walter Cunningham	10 : 20 : 9	First U.S. 3-man mission.
Soyuz 3	26 Oct. 1968	Georgiy T. Beregovoy	3 : 22 : 51	Maneuvered near unmanned Soyuz 2.
Apollo 8	21 Dec. 1968	Frank Borman James A. Lovell, Jr. William A. Anders	6 : 3 : 1	First manned orbit(s) of moon; first manned departure from earth's sphere of influence; highest speed ever attained in manned flight.
Soyuz 4	14 Jan. 1969	Vladimir A. Shatalov	2 : 23 : 23	Soyuz 4 and 5 docked and transferred 2 cosmonauts from Soyuz 5 to Soyuz 4.
Soyuz 5	15 Jan. 1969	Boris V. Volynov Aleksey S. Yeliseyev Yevgeniy V. Khrunov	3 : 0 : 56	
Apollo 9	3 Mar. 1969	James A. McDivitt David R. Scott Russell L. Schweickart	10 : 1 : 1	Successfully simulated in earth orbit operation of lunar module to landing and takeoff from lunar surface and rejoining with command module.
Apollo 10	18 May 1969	Thomas P. Stafford John W. Young Eugene A. Cernan	8 : 0 : 3	Successfully demonstrated complete system including lunar module descent to 14 300 m from the lunar surface.
Apollo 11	16 July 1969	Neil A. Armstrong Michael Collins Edwin E. Aldrin, Jr.	8 : 3 : 9	First manned landing on lunar surface and safe return to earth. First return of rock and soil samples to earth, and manned deployment of experiments on lunar surface.
Soyuz 6	11 Oct. 1969	Georgiy Shonin Valeriy N. Kubasov	4 : 22 : 42	Soyuz 6, 7, and 8 operated as a group flight without actually docking. Each conducted certain experiments, including welding and earth and celestial observation.
Soyuz 7	12 Oct. 1969	Anatoliy V. Filipchenko Viktor N. Gorbatko Vladislav N. Volkov	4 : 22 : 41	
Soyuz 8	13 Oct. 1969	Vladimir A. Shatalov Aleksey S. Yeliseyev	4 : 22 : 50	

U.S. and Soviet Manned Spaceflights 1961–1981

Spacecraft	Launch Date	Crew	Flight Time (days : hrs : min)	Highlights
Apollo 12	14 Nov. 1969	Charles Conrad, Jr. Richard F. Gordon, Jr. Alan L. Bean	10 : 4 : 36	Second manned lunar landing. Explored surface of moon and retrieved parts of Surveyor 3 spacecraft, which landed in Ocean of Storms on 19 Apr. 1967.
Apollo 13	11 Apr. 1970	James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr.	5 : 22 : 55	Mission aborted; explosion in service module. Ship circled moon, with crew using LM as "lifeboat" until just before reentry.
Soyuz 9	1 June 1970	Andriyan G. Nikolayev Vitaliy I. Sevastyanov	17 : 16 : 59	Longest manned spaceflight to date.
Apollo 14	31 Jan. 1971	Alan B. Shepard, Jr. Stuart A. Roosa Edgar D. Mitchell	9 : 0 : 2	Third manned lunar landing. Mission demonstrated pinpoint landing capability and continued manned exploration.
Soyuz 10	22 Apr. 1971	Vladimir A. Shatalov Aleksey S. Yeliseyev Nikolay N. Rukavishnikov	1 : 23 : 46	Docked with Salyut 1, but crew did not board space station launched 19 Apr. Crew recovered 24 Apr. 1971.
Soyuz 11	6 June 1971	Georgiy T. Dobrovolskiy Vladislav N. Volkov Viktor I. Patsayev	23 : 18 : 22	Docked with Salyut 1 and Soyuz 11 crew occupied space station for 22 days. Crew perished during final phase of Soyuz 11 capsule recovery on 30 June 1971.
Apollo 15	26 July 1971	David R. Scott Alfred M. Worden James B. Irwin	12 : 7 : 12	Fourth manned lunar landing and first Apollo "J" series mission, which carried Lunar Roving Vehicle. Worden's in-flight EVA of 38 min 12 sec was performed during return trip.
Apollo 16	16 Apr. 1972	John W. Young Charles M. Duke, Jr. Thomas K. Mattingly II	11 : 1 : 51	Fifth manned lunar landing, with Lunar Roving Vehicle.
Apollo 17	7 Dec. 1972	Eugene A. Cernan Harrison H. Schmitt Ronald E. Evans	12 : 13 : 52	Sixth and final Apollo manned lunar landing, again with roving vehicle.
Skylab 2	25 May 1973	Charles Conrad, Jr. Joseph P. Kerwin Paul J. Weitz	28 : 0 : 50	Docked with Skylab 1 for 28 days. Repaired damaged station.
Skylab 3	28 July 1973	Alan L. Bean Jack R. Lousma Owen K. Garriott	59 : 11 : 9	Docked with Skylab 1 for more than 59 days.
Soyuz 12	27 Sept. 1973	Vasiliy G. Lazarev Oleg G. Makarov	1 : 23 : 16	Checkout of improved Soyuz.
Skylab 4	16 Nov. 1973	Gerald P. Carr Edward G. Gibson William R. Pogue	84 : 1 : 16	Docked with Skylab 1 in long-duration mission; last of Skylab program.
Soyuz 13	18 Dec. 1973	Petr I. Klimuk Valentin V. Lebedev	7 : 20 : 55	Astrophysical, biological, and earth resources experiments.
Soyuz 14	3 July 1974	Pavel R. Popovich Yuriy P. Artyukhin	15 : 17 : 30	Docked with Salyut 3 and Soyuz 14 crew occupied space station.
Soyuz 15	26 Aug. 1974	Gennadiy V. Sarafanov Lev S. Demin	2 : 0 : 12	Rendezvoused but did not dock with Salyut 3.
Soyuz 16	2 Dec. 1974	Anatoliy V. Filipchenko Nikolay N. Rukavishnikov	5 : 22 : 24	Test of ASTP configuration.
Soyuz 17	10 Jan. 1975	Aleksey A. Gubarev Georgiy M. Grechko	29 : 13 : 20	Docked with Salyut 4 and occupied station.
Anomaly	5 Apr. 1975	Vasiliy G. Lazarev Oleg G. Makarov	0 : 0 : 20	Soyuz stages failed to separate; crew recovered after abort.
Soyuz 18	24 May 1975	Petr I. Klimuk Vitaliy I. Sevastyanov	62 : 23 : 20	Docked with Salyut 4 and occupied station.
Soyuz 19	15 July 1975	Aleksey A. Leonov Valeriy N. Kubasov	5 : 22 : 31	Target for Apollo in docking and joint experiments of ASTP mission.
Apollo	15 July 1975	Thomas P. Stafford Donald K. Slayton Vance D. Brand	9 : 1 : 28	Docked with Soyuz 19 in joint experiments of ASTP mission.
Soyuz 21	6 July 1976	Boris V. Volynov Vitaliy M. Zholobov	48 : 1 : 32	Docked with Salyut 5 and occupied station.
Soyuz 22	15 Sept. 1976	Valeriy F. Bykovskiy Vladimir V. Aksenov	7 : 21 : 54	Earth resources study with multispectral camera system.
Soyuz 23	14 Oct. 1976	Vyacheslav D. Zudov Valeriy I. Rozhdestvenskiy	2 : 0 : 6	Failed to dock with Salyut 5.
Soyuz 24	7 Feb. 1977	Viktor V. Gorbato Yuriy N. Glazkov	17 : 17 : 23	Docked with Salyut 5 and occupied station.
Soyuz 25	9 Oct. 1977	Vladimir V. Kovalenok Valeriy V. Ryumin	2 : 0 : 46	Failed to achieve hard dock with Salyut 6 station.

U.S. and Soviet Manned Spaceflights 1961–1981

Spacecraft	Launch Date	Crew	Flight Time (days : hrs : min)	Highlights
Soyuz 26	10 Dec. 1977	Yuriy V. Romanenko	37 : 10 : 6	Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 96 days 10 hrs.
Soyuz 27	10 Jan. 1978	Georgiy M. Grechko	64 : 22 : 53	Docked with Salyut 6. Crew returned in Soyuz 26; crew duration 5 days 22 hrs 59 min.
Soyuz 28	2 Mar. 1978	Vladimir A. Dzhanibekov	7 : 22 : 17	Docked with Salyut 6. Remek was first Czech cosmonaut to orbit.
Soyuz 29	15 June 1978	Oleg G. Makarov	79 : 15 : 23	Docked with Salyut 6. Crew returned in Soyuz 31; crew duration 139 days 14 hrs 48 min.
Soyuz 30	27 June 1978	Aleksey A. Gubarev	7 : 22 : 4	Docked with Salyut 6. Hermaszewski was first Polish cosmonaut to orbit.
Soyuz 31	26 Aug. 1978	Vladimir Remek	67 : 20 : 14	Docked with Salyut 6. Crew returned in Soyuz 29; crew duration 7 days 20 hrs 49 min. Jaehn was first German Democratic Republic cosmonaut to orbit.
Soyuz 32	25 Feb. 1979	Vladimir V. Kovalenok	108 : 4 : 24	Docked with Salyut 6. Crew returned in Soyuz 34; crew duration 175 days 36 min.
Soyuz 33	10 Apr. 1979	Aleksandr S. Ivanchenkov	1 : 23 : 1	Failed to achieve docking with Salyut 6 station. Ivanov was first Bulgarian cosmonaut to orbit.
Soyuz 34	6 June 1979	Petr I. Klimuk	73 : 18 : 17	Docked with Salyut 6, later served as ferry for Soyuz 32 crew while Soyuz 32 returned unmanned.
Soyuz 35	9 Apr. 1980	Miroslaw Hermaszewski	55 : 1 : 29	Docked with Salyut 6. Crew returned in Soyuz 37. Crew duration, 184 days 20 hrs 12 min.
Soyuz 36	26 May 1980	Valeriy F. Bykovskiy	65 : 20 : 54	Docked with Salyut 6. Crew returned in Soyuz 35. Crew duration 7 days 20 hrs 46 min. Farkas was first Hungarian to orbit.
Soyuz T-2	5 June 1980	Sigmund Jaehn	3 : 22 : 21	Docked with Salyut 6. First manned flight of new-generation ferry.
Soyuz 37	23 July 1980	Leonid I. Popov	79 : 15 : 17	Docked with Salyut 6. Crew returned in Soyuz 36. Crew duration 7 days 20 hrs 42 min. Pham was first Vietnamese to orbit.
Soyuz 38	18 Sept. 1980	Valeriy V. Ryumin	7 : 20 : 43	Docked with Salyut 6. Tamayo was first Cuban to orbit.
Soyuz T-3	27 Nov. 1980	Valeriy N. Kubasov	12 : 19 : 8	Docked with Salyut 6. First 3-man flight in Soviet program since 1971.
Soyuz T-4	12 Mar. 1981	Bertalan Farkas	74 : 18 : 38	Docked with Salyut 6.
Soyuz 39	22 Mar. 1981	Yuriy V. Malyshev	7 : 20 : 43	Docked with Salyut 6. Gurragecha first Mongolian cosmonaut to orbit.
Space Shuttle Columbia (STS 1)	12 Apr. 1981	Vladimir V. Aksenov	2 : 6 : 21	First flight of Space Shuttle, tested spacecraft in orbit. First landing of airlanelike craft from orbit for reuse.
Soyuz 40	14 May 1981	Viktor P. Savinykh	7 : 20 : 41	Docked with Salyut 6. Prunariu first Romanian cosmonaut to orbit.
Space Shuttle Columbia (STS 2)	12 Nov. 1981	Vladimir A. Dzhanibekov	2 : 6 : 13	Second flight of Space Shuttle, first scientific payload (OSTA 1). Tested remote manipulator arm. Returned for reuse.

U.S. Space Launch Vehicles

Vehicle	Stages	Propellant ^a	Thrust (kilo- newtons)	Max. Dia. × Height (m)	Max. Payload (kg) ^b			First Launch ^c
					185-Km Orbit	Geosynch.- Transfer Orbit	Circular Sun-Synch. Orbit	
Scout	1. Algol IIIA	Solid	484.5	1.14 × 22.9	255	—	155 ^d	1979(60)
	2. Castor IIA	Solid	285.2		205 ^d			
	3. Antares IIIA	Solid	83.1					
	4. Altair IIIA	Solid	25.6					
Delta 2900 Series (Thor-Delta)	1. Thor plus	LOX/RP-1	912.0	2.44 × 35.4	2 000	705	1 250 ^d	1973(60)
	9 TX 354-5	Solid	147 each		1 410 ^d			
	2. Delta	N ₂ O ₄ /Aerozine-50	44.2					
	3. TE 364-4	Solid	65.8					
Delta 3900 Series (Thor-Delta) ^e	1. Thor plus	LOX/RP-1	912.0	2.44 × 35.4	3 045	1275	2 135 ^d	1982(60)
	9 TX 526-2	Solid	375 each		2 180 ^d			
	2. Delta	N ₂ O ₄ /Aerozine-50	44.2					
	3. TE 364-4	Solid	65.8					
Atlas E/F- TE 364-4	1. Atlas booster & sustainer	LOX/RP-1	1 722.0	3.05 × 28.1	2 090 ^{d f}	—	1 500 ^d	1972(67)
	2. TE 364-4	Solid	65.8					
Atlas-Centaur	1. Atlas booster & sustainer	LOX/RP-1	1 913.0	3.05 × 39.8	5 680	2045	—	1962
	2. Centaur	LOX/LH ₂	146.0					
					185-Km Orbit	Direct Geosynch. Orbit	Sun- Synch. Transfer Orbit	
Titan IIIB-Agena	1. LR-87	N ₂ O ₄ /Aerozine	2 341.0	3.05 × 48.4	3 600 ^d	—	3 060	1966
	2. LR-91	N ₂ O ₄ /Aerozine	455.1					
	3. Agena	IRFNA/UDMH	71.2					
Titan IIIC	1. Two segment 3.05-m dia.	Solid	10 675.2	3.05 × 48.2	13 245	1610 ^d	—	1965
	2. LR-87	N ₂ O ₄ /Aerozine	2 341.0					
	3. LR-91	N ₂ O ₄ /Aerozine	455.0					
	4. Transtage	N ₂ O ₄ /Aerozine	69.8					
Titan IIID	Same as Titan IIIC without Transtage			3.05 × 46.9	11 020 ^d	—	99 750 ^d	1971
Titan III(34)D	1. Two 5½-segment 3.05-m dia.	Solid	11 564.8	3.05 × 49.4	12 520 ^d	—	11 340 ^d	g
	2. LR-87	N ₂ O ₄ /Aerozine	2 366.3					
	3. LR-91	N ₂ O ₄ /Aerozine	449.3					
Titan III(34) D/IUS	Same as Titan III (34)D plus:			3.05 × 48.0	14 920	1850 ^d	—	1982
	4. IUS 1st Stage	Solid	275.8					
	5. IUS 2nd Stage	Solid	115.7					
Titan III(34)D 4. Transtage	Same as Titan III(34) plus: Transtage			3.05 × 46.9	14 920	1855 ^d	—	h
					280- to 420-Km Orbit			
Space Shuttle (reusable)	1. Orbiter; 3 main engines (SSMEs) fire in parallel with SRBs	LOX/LH ₂	1 670 each	23.79 × 37.24 wing long span	29 500 in full performance configuration			1981
	2. Two-solid-fueled rocket boosters (SRSs) fire in parallel with SSMEs	Al/NH ₄ ClO ₄ / PBAN	11 790 each	3.80 × 45.46				
	Mounted on ex- ternal tank (ET)			8.40 × 47.00				

^a Propellant abbreviations used are as follows: liquid oxygen and a modified kerosene = LOX/RP-1; solid propellant combining in a single mixture both fuel and oxidizer = solid; inhibited red fuming nitric acid and unsymmetrical dimethylhydrazine = IRFNA/UDMH; nitrogen tetroxide and UDMH/N₂H₄ = N₂O₄/Aerozine; liquid oxygen and liquid hydrogen = LOX/LH₂; aluminum, ammonium perchlorate, and polybutadiene acrolonitrile terpolymer = AL/NH₄CLO₄/PBAN.

^b Due east launch.

^c The date of first launch applies to this latest modification with a

date in parentheses for the initial version.

^d Polar launch.

^e Maximum performance based on 3920, 3920/PAM configurations. PAM = payload assist module (a private venture).

^f With dual TE 364-4.

^g Initial operational capability in December 1981; launch to be scheduled as needed.

^h Initial operational capability in December 1982; launch to be scheduled as needed.

ⁱ At sea level.

NOTE: In no instance should these data be used for detailed NASA mission planning without concurrence of the director of expendable launch vehicles.

Space Activities of the U.S. Government

HISTORICAL BUDGET SUMMARY—BUDGET AUTHORITY

(in millions of dollars)

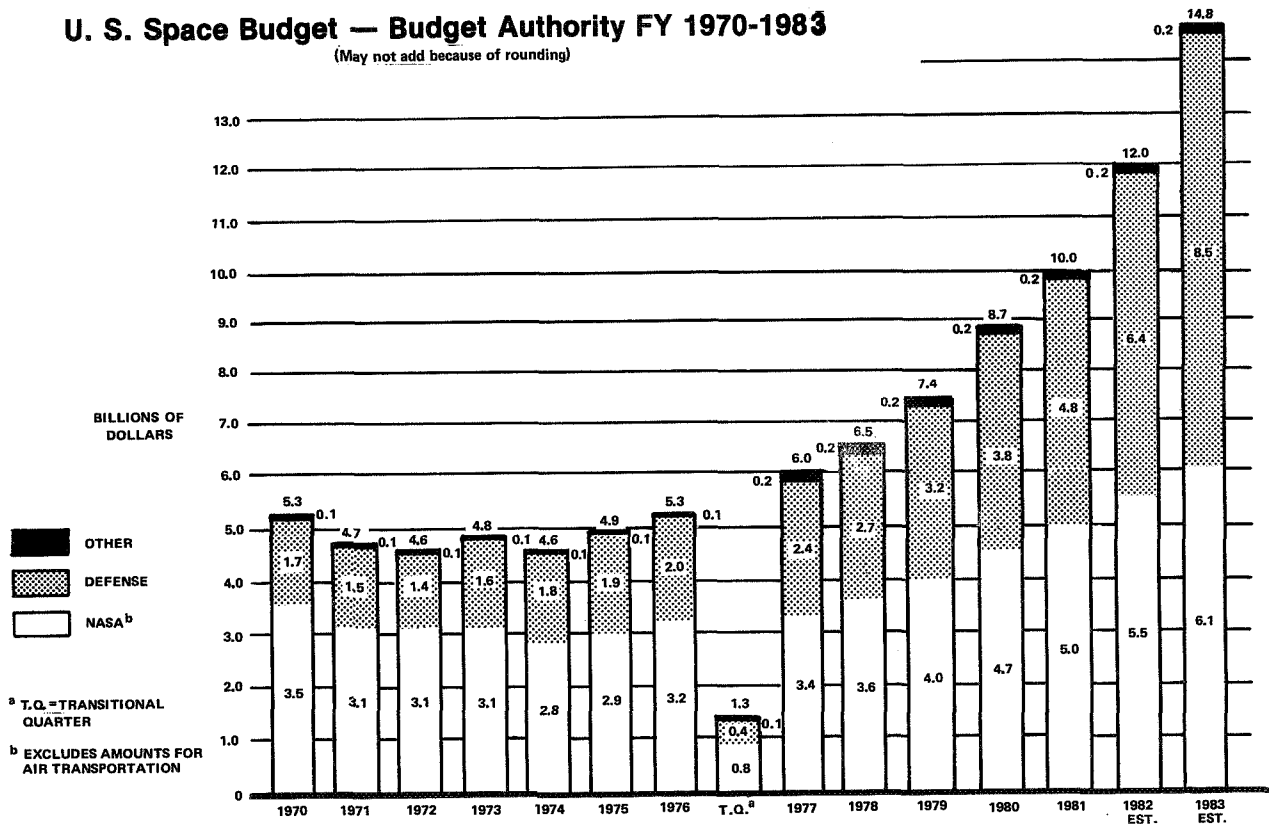
Fiscal Year	NASA		Defense	Energy	Com- merce	Interior	Agricul- ture	NSF	Total Space
	Total	Space ^a							
1959	330.9	260.9	489.5	34.3	...	...	...	...	784.7
1960	523.6	461.5	560.9	43.3	...	...	...	0.1	1065.8
1961	964.0	926.0	813.9	67.7	...	...	...	.6	1808.2
1962	1824.9	1796.8	1298.2	147.8	50.7	...	...	1.3	3294.8
1963	3673.0	3626.0	1549.9	213.9	43.2	...	...	1.5	5434.5
1964	5099.7	5016.3	1599.3	210.0	2.8	...	...	3.0	6831.4
1965	5249.7	5137.6	1573.9	228.6	12.2	...	...	3.2	6955.5
1966	5174.9	5064.5	1688.8	186.8	26.5	...	...	3.2	6969.8
1967	4965.6	4830.2	1663.6	183.6	29.3	...	...	2.8	6709.5
1968	4587.3	4430.0	1921.8	145.1	28.1	0.2	0.5	3.2	6528.9
1969	3990.9	3822.0	2013.0	118.0	20.0	.2	.7	1.9	5975.8
1970	3745.8	3547.0	1678.4	102.8	8.0	1.1	.8	2.4	5340.5
1971	3311.2	3101.3	1512.3	94.8	27.4	1.9	.8	2.4	4740.9
1972	3306.6	3071.0	1407.0	55.2	31.3	5.8	1.6	2.8	4574.7
1973	3406.2	3093.2	1623.0	54.2	39.7	10.3	1.9	2.6	4824.9
1974	3036.9	2758.5	1766.0	41.7	60.2	9.0	3.1	1.8	4640.3
1975	3229.1	2915.3	1892.4	29.6	64.4	8.3	2.3	2.0	4914.3
1976	3550.3	3225.4	1983.3	23.3	71.5	10.4	3.6	2.4	5319.9
Transitional Quarter	931.8	849.2	460.4	4.6	22.2	2.6	.9	.6	1340.5
1977	3817.8	3440.2	2411.9	21.7	90.8	9.5	6.3	2.4	5982.8
1978	4060.1	3622.9	2728.8	34.4	102.8	9.7	7.7	2.4	6508.7
1979	4595.5	4030.4	3211.3	58.6	98.4	9.9	8.2	2.4	7419.2
1980	5240.2	4680.4	3848.4	39.6	92.6	11.7	13.7	2.4	8688.8
1981	5518.4	4992.4	4827.7	40.5	87.0	12.3	15.5	2.4	9977.8
1982 est.	5935.6	5462.0	6386.9	37.6	125.0	11.9	15.3	2.0	12040.7
1983 est.	6608.0	6121.7	8501.9	30.6	151.0	9.5	22.8	1.5	14839.0

^a Excludes amounts for air transportation (subfunction 402).

SOURCE: Office of Management and Budget.

U. S. Space Budget — Budget Authority FY 1970-1983

(May not add because of rounding)



SOURCE: OFFICE OF MANAGEMENT AND BUDGET

Space Activities Budget

(in millions of dollars by fiscal year)

Federal Space Programs	Budget Authority			Outlays		
	1981 Actual	1982 Est.	1983 Est.	1981 Actual	1982 Est.	1983 Est.
Federal agencies:						
NASA ^a	4 992.4	5 462.0	6 121.7	4 877.1	5 282.4	6 061.6
Defense	4 827.7	6 386.9	8 501.9	4 130.5	5 112.8	6 477.1
Energy	40.5	37.6	30.6	46.9	43.1	31.1
Commerce	87.0	125.0	151.0	81.0	122.0	147.0
Interior	12.3	11.9	9.5	12.1	11.7	9.3
NSF	2.4	2.0	1.5	2.4	2.2	2.0
Agriculture	15.5	15.3	22.8	15.5	15.3	22.8
Total	9 977.8	12 040.7	14 839.0	9 165.5	10 589.5	12 750.9
NASA:						
Space flight	3 187.2	3 577.6	3 983.1	3 053.3	3 461.7	3 991.6
Space science, applications, and technology	1 359.1	1 381.2	1 525.8	1 384.3	1 344.4	1 461.8
Air transportation	526.0	473.6	486.3	544.2	544.2	515.5
Supporting operations	450.4	507.6	617.7	443.8	480.7	613.1
Less receipts	-4.3	-4.4	-4.9	-4.2	-4.4	-4.9
Total NASA	5 518.4	5 935.6	6 608.0	5 421.4	5 826.6	6 577.1

^a Excludes amounts for air transportation.

SOURCE: Office of Management and Budget.

Aeronautics Budget

(in millions of dollars by fiscal year)

Federal Aeronautics Programs	Budget Authority		
	1981 Actual	1982 Est.	1983 Est.
NASA ^a	526.0	473.6	486.3
Department of Defense ^b	2653.3	2983.6	3664.1
Department of Transportation ^c	106.2	80.6	133.5
Total	3285.5	3537.8	4283.9

^a Research and Development, Construction of Facilities, Research and Program Management.

^b Research, Development, Testing, and Evaluation of aircraft and related equipment.

^c Federal Aviation Administration Research, Engineering, and

Development and Facilities, Engineering and Development. The 1982 estimate assumes enactment of a proposed \$16 million supplemental and the 1983 estimate assumes enactment of pending authorization and user fee legislation.

SOURCE: Office of Management and Budget.